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SEEDING MANAGEMENT TO INCREASE AND STABILIZE CANOLA PRODUCTION IN THE SEMIARID PRAIRIE

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Seeding Management to Increase and Stabilize Canola Production in the Semiarid Prairie

Final Report For
The Saskatchewan Agriculture Development Fund &
The Saskatchewan Canola Development Commission

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A. ABSTRACT

In the semiarid Brown soil zone, improving the economics of growing canola requires adopting practices that promote more efficient use of water such as seeding into tall standing cereal stubble and seeding early to avoid heat and water stress during July and August. Deciding when a canola stand requires reseeding has been a perennial question in the Brown soil zone, and making this assessment is especially important for fall- or early-spring seeded canola. Therefore, to determine the effect of seeding management, stubble management and population densities on the productivity of canola and mustard in the Brown soil zone, field experiments were conducted at Swift Current during 1998-1999, 1999-2000, and 2000-2001. Generally, with adequate fertility and water, grain yields and water use efficiencies of fall seeded canola and mustard were similar to those for early spring-seeded canola and mustard and greater than those when seeded later in sping. As well, grain yields and water use efficiency tended to be higher when seeded into tall compared to short stubble and significantly lower when seeded into cultivated stubble. However, yield benefits were greater when canola in tall stubble was fertilized with an extra 34 Kg ha^{-1} N. Canola maintained seed yield over a wide range of populations. Seed yield declined with populations less than 40 pl m^{-2}. On average, compared to early spring seeding, late spring seeding reduce canola yield by >30%; on average, when seeded in early spring, compared to optimum plant densities of >80 pl m^{-2}, canola yields were reduced by 20% at a plant population of 20 pl m^{-2}. Therefore, 20 pl m^{-2} is a reasonable threshold population for re-seeding of early spring seeded canola in the semiarid prairie.

B. EXECUTIVE SUMMARY

Canola production in the semiarid prairie is susceptible to high temperature and water stress. Compared to late spring seeding, canola planted late fall or early spring completes a larger portion of its' growth and development during the cooler and moister spring and early summer thereby reducing the heat and water stress levels at the critical flowering stage. Leaving stubble standing over winter improves soil moisture conservation by snow trapping, and seeding directly into standing stubble improves crop growth and water use efficiency by creating a more favorable microclimate for crop growth. The benefits of standing stubble depend on its height. Achieving good plant stand establishment of any crop with small seeds is a challenge due to the harsh environments of the semiarid prairie. For example, seeding earlier than is traditionally accepted increases the risk of frost injury to emerging plants and seedlings; severe forest injury may kill young seedlings. Therefore, information on the threshold population for reseeding is required.

The main goals of this research were to: 1) compare yield and water use efficiencies of different canola and mustard species, when seeded at different dates-late fall, early and late spring and of Argentine canola seeded into stubble of various heights-cultivated, short (15 cm high) and tall (>30 cm high) stubble, and 2) to determine the relationship between suboptimal plant populations and yield to determine the conditions under which re-seeding becomes advantageous. The secondary objective was to evaluate the heat-balance sap flow system for measuring the realtime water use of canola under varying environments.

This study was initiated in the fall of 1998 on silt loam soil at the Semiarid Prairie Agricultural Research Centre at Swift Current. Three field experiments, dates of seeding

(both on fallow and on stubble), stubble management (managed with field scale equipment), and population test were conducted during the 1998-1999, 1999-2000, and 2000-2001 seasons.

Fall and early spring seeding increased seed yield by >30% compared to late spring seeding, showing the value of early seeding to increase canola and mustard seed yields in the Brown soil zone. Plant populations with early seeding dates were low, but the yield adjustment of canola and mustard species compensated for the sparse populations. Generally, all four species responded similarly to seeding dates. Although fall seeding reduced water use in some cases, the efficiency of water use increased with fall and early spring compared to late spring seeding. In the extremely dry year of 2001, the response of canola and mustard to seeding date was noticeably dependent upon the timing of rainfall events; however, the highest yield occurred when canola was seeded in early spring.

Tall standing stubble modified the canola microclimate significantly by reducing wind speed at the 15 cm height, by cooling soil temperature at the 5 cm soil depth and by reducing solar radiation reaching the soil surface. Tall stubble tended to have better crop establishment compared to cultivated stubble, although biomass at harvest and water use did not show any effect of stubble height. Averaged across the three seasons, tall stubble and tall stubble+extra fertilizer significantly increased seed yield by 21 and 39%, respectively. Seeding dates interacted with stubble treatments and yield improvement with tall stubble and tall stubble+extra fertilizer were higher in the fall compared to late spring. Thus, seeding into tall stubble is a potential management practice to increase canola productivity in the semiarid prairie. The greater yield response with tall stubble+extra fertilizer, however, necessitates more studies with tall stubble to ascertain optimum fertilizer requirements.

Argentine canola exhibits a high degree of yield plasticity, thus as the population decreases, each plant grows larger and produces more fertile branches and more pods. This compensating activity can maintain yields over a wide range of populations. However, availability of resources (mainly water) limits the expression of yield plasticity. Reducing population by 50% from 80 to 40 plants m^{-2} and non-uniform plant stand had no effect on seed yield. Further decreasing plant population to 20 plants m^{-2} reduced seed yield by <20%. Since seeding in late spring reduced seed yield by >30% (chapter 1), a population of 20 plants m^{-2} would be a reasonable threshold for re-seeding canola in the semiarid prairie. The main response of canola to lower plant populations was to increase branches and pods per plant, while the effect on seeds per pod and seed weight was small. At higher plant populations, most of the pods were produced on the upper part of the canopy and as the population decreased, contributions to grain yield from the lower nodes and/or secondary and higher order branches increased. Because the main shoot and upper branches reach maturity earlier than the lower branches, depending on the growing conditions, crops with higher plant populations will tend to mature earlier by a few days than crops with lower populations that tend to have bushier plants with a higher proportion of lower branches.

The heat-balance sap flow system is a new technology for measuring real-time water use by plants. The results indicated a strong relationship between sap flow and transpiration. Because of the strong relationship between sap flow and transpiration, we were able to measure water use by canola over short periods of one hour and over longer periods of one day in response to variations in temperature and solar radiation. Thus, the sap flow system was useful for quantifying transpiration in canola. The heat-balance sap flow system will be a useful tool for measuring real-time water use in agronomic and physiologic studies of crop growth and development.

The results of this study clearly indicate that simple and easy to implement technologies such as fall or early-spring seeding and seeding directly into tall standing stubble are highly successful technologies for growing canola and offer greater income stabilization and a better fit of canola as a crop for the Brown soil zone. The low and non-uniform canola population performed better than expected because of canolas' tremendous plasticity. As well, we suggest that a population of 20 plants m^{-2} should be the threshold for re-seeding canola in the semiarid prairie. The year 2001, being 2nd driest and 5th warmest since 1883, was atypical for Swift Current and changed some of the key responses of canola. Therefore, we recommend that the seeding date and stubble management experiments be conducted for one more year, before solid recommendations are made.

C. TECHNICAL REPORT

General Comments:

The year 1999 tended to be slightly cooler and wetter than typical years on the southern Prairie (Table 2.1). At seeding, soil water was adequate with profile filled to above 50 %. Fall seeded Brassica species started emerging during first week of May. A good snow storm during second week of may dumped significant amount of snow. However, Brassica seedlings survived snow. After that, regular rainfall and lower than average temperatures did not impose any significant stress till August, when rainfall stopped. By that time, earlier seeding dates were harvested and late spring crop had passed critical stages for water stress. Grain yields were much higher than the yields realized in this region.

The late fall-early spring soil profile was relatively dry in 2000. Although total precipitation during the season was slightly above normal, distribution was uneven. May and June received about 30% less rainfall compared to previous year, while July received more than double the rainfall of 1999 season. Fall seeded Brassica species started emerging during the last week of April. Yellow mustard emerged about 1 week before the other species, indicating the ability of the species to quickly establish under adverse conditions. Similar to the previous year, a snow storm during second week of May deposited significant amounts of snow. However, the Brassica seedlings survived. Average temperatures were also higher than for the 1999 season. Rainfall stopped abruptly in the third week of July. Thus, the rainfall distribution in 2000 was more favorable for the early spring seeded crop than the late fall seeded crop.

The soil profile in 2001 was extremely dry at seeding, especially on previously cropped land. Fall seeded canola had to emerge from a dry, crusted soil surface which delayed emergence and resulted in tremendous variations in population and growth stage within the fall-seeded plots; emergence continued from the end of April to mid-June. Thus, some observations like plant counts and biomass were unreliable from many fall seeded plots. The first half of the growing season was very dry (Table 1) but there was enough seed-bed soil moisture to ensure better crop establishment for the early and late spring seeding dates. However, overall crop establishment was poor compared to the previous two years.

The results of all these trials are presented in four different chapters. The first chapter deals with the response of canola and mustard to seeding dates, the second chapter describes canola response to stubble height, the third chapter reports on the response of canola to uniform and non-uniform plant populations, and the fourth chapter shows the feasibility of using the heat-balance sap flow system to measure real-time transpiration of canola.

CHAPTER 1

Seeding Management to Improve Sustainability of Canola and Mustard Production in the Semiarid Prairie

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Abstract

Canola production in the heat and water stress prone semiarid prairie is increasing. To sustain canola or mustard production, technologies that reduce the effect of heat and water stress on the canola and mustard crops are needed. Fall or early spring seeding can be used to reduce stress effects relative to the spring seeded crop. In addition, the optimum environments for different canola and mustard species may be different. Therefore, a field study was conducted for three seasons (fall 1998 to spring 2001) to determine if late fall or early spring seeding increased yields compared to traditional spring seeding and whether different Brassica spp. Responded similarly to alternate seeding dates. Four canola and mustard crop cultivars belonging to four different species (the fourth species was added in the second season) were seeded during late fall (November: just before freeze-up), early spring (last week of April) and late spring (middle of May). Fall seeding advanced the growing season and flowering times in all species. Plant population was generally poor with alternate seeding dates, especially with fall seeding. Early spring and late fall seeding pooled over three common species increased seed yield over later spring seeding by 53 and 36% in fallow trials and 82 and 31% in stubble trials, respectively. These observations suggest that alternate seeding dates were efficient in reducing abiotic stress effects on canola and mustard. Generally, all four species responded similarly to seeding dates. Canola and mustard cultivars used limited water more efficiently when seeded in late-fall or early spring compared to the late spring seeding. Thus, seeding management presents an opportunity to improve sustainablity of canola and mustard production in the semiarid prairie.

1.1 Introduction

Limited water and high temperature are two major factors limiting crop productivity in the semiarid prairie. Traditionally, the growing season for annual crops on the Prairie is from May to August (Fig.1.1). The precipitation deficit increases during the growing season, especially after July, and flowering usually occurs during the peak temperature period (Fig. 1.2).Thus, water and/or heat stress are major yield reducing factors for mid May seeded crops.

Seeding management can be used to reduce heat and water stress in canola and mustard. Fall or dormant seeding is a technology where seeds are planted into the soil just before freeze up, so that the seeds remain dormant in the frozen soil until the following spring and emerge at the earliest opportunity of favourable conditions (Kirkland and Johnson 2000). Thus, advancing the crop growing season by 30 days helps in avoiding high temperature stress and water stress at critical stages. Fall seeding has been tried with Argentine canola for some time (Bowren and Pittman, 1975). But a lack of good in-crop weed control technology was major deterrent to the adoption of fall seeding technology by producers. Therefore, the development of herbicide tolerant cultivars has renewed the interest of producers in late-fall seeding. Early spring seeding, similar to fall seeding, has been found to advance the growing season by 18 days (Kirkland and Johnson 2000). Benefits of fall and early spring seeding include reducing heat and/or water stress at flowering, more efficient use of limited water, advanced maturity, reduced disease and pest problems, and spreading the workload. Successful adaptation of a crop to the environment involves reducing unfavourable risk factors and increasing favourable factors like optimum radiation, temperature and moisture conditions (Mendham and Salisbury 1995). Therefore, in the semiarid prairie where crop choice is limited due to the susceptibility of many crops to abiotic stresses, fall and early spring seeding has a significant role in the designing and implementation of various cropping systems.

Cropping systems in the semiarid prairie are changing. Oilseed and pulse crops are being added to the crop rotation. Due to the better economics, canola is occupying the oilseed component of the rotation. However, canola is a cool season crop and is susceptible to heat stress. Oriental mustard is more stress tolerant than canola and is recommended to replace canola in the semiarid prairie. No information is available on the yellow mustard's response to altered seeding dates that include late-fall seeding. Therefore, it is necessary to study the response of different canola and mustard species to seeding dates with special emphasis on fall seeding.

Therefore, the objectives of this study were to examine the effect of fall and spring seeding on the growth and water use characters of three Brassica species, and to compare the yield responses of three Brassica species to fall and spring seeding under fallow and stubble conditions.

1.2 Materials and Methods

The experiment was conducted on a Swinton loam soil (Orthic Brown Chernozem) at the Agriculture and Agri-Food Canada, Semiarid Prairie Agricultural Research Centre (SPARC), Swift Current over three seasons (1998-1999, 1999-2000 and 2000-2001). Four canola and mustard species, Argentine canola (*Brassica napus* L.; cv. 'Arrow'), Polish canola (*B. rapa* L.; cv. 'Sunbeam'), oriental mustard (*B. juncea* L. Coss.; cv. 'Cutlass') and yellow mustard (*Synapsis alba* L; cv. 'Pennant') were compared for seeding responses. The seeding dates were late fall (Nov 2 to 23) (just before freeze-up), early spring (April 24 to 26) and late spring (May 23 to 25).

The experimental design was a factorial RCBD design with 3 replications. Each year the trial was run both on standing stubble and chemical fallow. Each plot consisted of 8 rows of 0.23 m apart and 10 m long. Seeding was done using an air drill, except in fall of 1999 when a disc drill was used to seed into frozen soil. A High seeding rate of 10 kg ha^{-1} (13 kg ha^{-1} for yellow mustard) was used to get an acceptable stand, especially from fall and early spring seeded crops. Vitavax RS (carbathiin + thiram + lindane) seed treatment was used to control seedling fungal diseases and provide protection against flea beetles. Each year, 77 kg N and 22 kg S ha^{-1} were broadcasted in the spring, while 22 kg ha^{-1} P and a small amount of N (6 kg ha^{-1}) were side banded while seeding.

Plant populations were determined from 1 m^2 area after crop emergence. However, year 2001 was extremely dry, and crop emergence varied and plant populations were difficult to determine. For example, the fall seeded crop emerged between from late April to mid June. Therefore, plant counts taken in 2001 were not presented. At harvest, plants from 1 m^2 were hand harvested from two rows to assess biomass production and harvest index. A plot combine was used to harvest the middle 6 rows for seed yield measurements. In the stubble phase, soil moisture was measured (except in 2001) with a neutron probe to a depth of 1.80m. Soil moisture in the fallow phase and in the stubble phase of 2001 was measured with gravimetrically.

Each year weather conditions varied significantly with the second driest yearsince 1883 occurring in 2001. Therefore, because of the tremendous weather variations between years, we analyzed the data on a yearly basis. However, the mean seed yield of cultivars used in all three years was analyzed to generalize the results. The data from stubble and fallow trials were also analyzed separately. A factorial RCBD design was used for statistical analysis.

1.3 Results and Discussion

1.3.1 Crop Establishment

Fall seeded canola and mustard species emerged in the third week of April, while early spring seeded crops emerged in first week of May. Availability of water for emergence is very important in this region. Water stress and surface crusting reduced the fall seeded population in 2001 to near zero (data not presented). Yellow mustard generally emerged earlier than other species across all seeding dates. In 2001, a few yellow mustard plants emerged from the fall seeded plots, while the other species failed completely.

In general, fall seeding had the lowest plant population, while the late spring (early spring in the 1999 fallow phase) had the highest plant population. Comparing seeding dates, significant differences in plant populations were observed more often in the fallow phase (1999 and 2000) than in the stubble phase (1999) (Table 1.1 to 1.3). Kirkland and Johnson (2000) made similar observations for Argentine canola. Canola germination is more sensitive to temperature than other crops like wheat and barley (Miralles et al. 2001). For example, canola takes 1 day to germinate at 21 to 25 °C, while it needs 11 to 14 days at 2 °C (Kondra et al. 1983). Thus, prolonged germination period, severe winter conditions, soil crusting, insect and pest damage might have contributed for the lower plant stands in fall and early spring seeded crops compared to late spring seeding, as reported by Kirkland and Johnson (2000). However, the very sparse plant stand in 2001 was due to soil crusting and extremely dry conditions. Soil crusting is a common problem in the loam soils of semiarid prairie. Kirkland and Johnson (2000) also reported that soil crusting reduced plant stand of fall seeded canola significantly in dry years.

Seeding by species interaction was only significant in the fallow phase during 1999. Thus, all species were responding to seeding practices similarly. Plant populations were normalized to the late spring seeded populations. The plant population in fall seeded plots in 1999 ranged from 37 to 82% of late spring seeded plots, the lowest being in sunbeam. Kondra et al. (1983) also observed lower germination percentages in B. rapa at low temperature stress compared to B. napus under laboratory conditions.

Fall seeding increased growing season duration by about 10-12 days compared to early spring seeding and by about 20-25 days compared to late spring seeding. Most of the extension in growing season occurred during cooler and moister weather (Fig. 1.1 and 1.2). Before the loss of moisture from surface soil layers due to increasing temperature and evaporation, the fall seeded crop was established with a well developed root system. The benefit of early seeding was also reflected in earlier flowering, avoiding mid to late summer heat stress. Kirkland and Johnson (2000) also reported early emergence and flowering by fall seeded Argentine canola. Further, they indicated that the duration of the reproductive stage was prolonged by fall and early spring compared to late spring seeding, while no effect on vegetative growth stage was observed.

1.3.2 Biomass and Seed Yield Production

Biomass production was significantly influenced by seeding practices (Tables 1.1 to 1.6). Biomass production by stubble phase was always lower than the fallow phase, indicating higher stress levels in stubble phase. Generally the species produced similar amounts of biomass, although cutlass tended to produce the highest biomass. The seeding date effect on biomass production did not follow population trends. For example, the fall seeded crop, in spite of lower populations, did not produce less biomass compared to the late spring seeded crop. This clearly indicates the compensatory growth in canola and mustards (Chapter 3). McGregor (1987) observed compensatory growth for canola grown on the Canadian prairie. Canola and mustard respond to higher temperature by hastening crop development (Mendham and Salisbury 1995). Compared to late spring seeding, the late fall or early spring seeded crops experienced cooler conditions,especially during the first half of the growing season which prolonged the developmental phase and increased biomass production.

Seed yield varied due to seeding date and species (Table 1.1 to 1.6). Averaging across the 3 years, the mean yield on fallow was 87 % higher than the mean yield on stubble (Table 1.7 and 1.8). In 1999, the average stubble yield was 72% of that on fallow, which reduced to 47% and 24% during 2000 and 2001. Drought during the previous winter and extreme drought as well as hot weather during the growing season were responsible for the very poor performance of canola and mustard in 2001. The mean seed yield on fallow trial of 2001 was only 35% of that in 1999, indicating the severity of the stress.

Comparing seeding dates and species effects separately for each year indicated significant seeding date effects in all trials, while the species effect was significant in some trials (Tables 1.1 to 1.6). Except under the extremely dry conditions of 2001, the species by seeding interaction was not significant, suggesting that all species were responding to seeding dates similarly. When resources were less limited, as in the fallow trials of 1999 and 2000, yields for fall seeding were either similar to or slightly better than yields for early spring seeding. Kirkland and Johnson (2000) made similar observations under the less stressful conditions at Scott (black soil zone). However, when the stress levels were higher as for the stubble trials and fallow trial in 2001, yields were greater for early spring seeding compared to fall seeding. Yield plasticity of canola and mustard is dependent opon the resource availability (such as temperature and water) (Diepenbrock 2000).Therefore, because of more limited resource availability, the yield compensation especially of fall seeded crops under high stress is probably lower than for early spring seeded crops. Late spring seeded canola and mustard yielded less than fall or early spring seeded canola and mustard, except for the extremely stressfull conditions of 2001 when yields for late spring seeding were as good or greater than yields for fall or early spring seeding.

Pooled over the three seasons and three common genotypes, early spring seeding increased yield over fall seeding by 13 and 39 %, and over late spring seeding by 53 and 82 % under fallow and stubble conditions, respectively (Table 1.7 to 1.8). The higher seed yield by early spring seeding over late fall seeding under fallow conditions was mainly due to the total failure of fall seeded Arrow in 2001, while early spring seeded Arrow in 2001 did exceedingly well. Therefore, fall seeding, which was either similar to or better than early spring seeding during the 1999 and 2000 fallow trials (Table 1.7 and 1.8), failed to perform as well as early spring seeding. This is an indication of the greater risk involved in fall seeding. Comparing late fall and early spring seeding under stubble conditions clearly indicates the better performance of the early spring seeding date. Lack of resources might have limited the yield compensation response under stubble conditions. Finally, the inconsistent results from fall seeding may also be related to seeding practices such as depth, soil cover, seeding equipment, etc. Seed placement and seed bed conditions are very critical to canola production, especially where conditions are marginal for canola production such as on the semiarid prairie. Producers need to be vigilant during the seeding operations, especially when fall seeding. For this reason, we recommend continued research into seeding requirements for fall seeding canola to improve the potential performance of this promising technology.

1.3.3 Water Use and Water Use Efficiency

In the semiarid environment of Swift Current, usually most of the available water in the soil is utilized by deeper rooted crops like canola or mustard. Therefore, the effect of seeding dates on the water use was very small (Tables 1.1 to 1.6). Whenever, significance was observed, fall seeding used less water than early spring or late spring crops. However, generally, there was no difference between species, an no difference between seeding dates with regards to water use; although sunbeam tended to use slightly less watercompared to the other species, and fall seeded crops tended to use slightly less water than the other seeding dates. Water use was affected by year and stubble phase. Compared to dry year 2001, the mean water use in 1999 and 2001 was 62 and 45% higher in fallow phase and 118 and 122%

higher in stubble phase, respectively. Relative water use in the stubble phase compared to the fallow phase also varied with year. For example, in 1999 and 2000 water used in stubble phase was above 85% of fallow phase, which reduced to 63% in 2001. Poor snow fall, small and delayed rainfall and higher temperatures characterized year 2001, which was the second driest and the fifth warmest in the recorded history of Swift Current (Judiesch and Cutforth, 2002).

In contrast, water use efficiency was significantly influenced by seeding dates and species (Table 1.1 to 1.6). For 1999 and 2000, when rainfall amounts and distribution were more typical for Swift Current, water use efficiency was lowest for the late spring seeding date. Generally, water use efficiency was similar when comparing between fall and early spring seeding dates. For the extremely dry 2001, water use efficiency was more dependent upon rainfall distribution. The late spring seeding date had the highest water use efficiency because of rains, which promoted more uniform seedling emergence and early growth. The higher water use efficiency of the early spring seeding date for fallow was because of the very high yield relative to the other species of Argentine canola cv. Arrow. This very high yield was probably due to the timing of a rainfall event corresponding to the flowering providing Arrow with water at a critical time for yield formation. The same yield boost for Arrow seeded early spring also occurred for stubble seeding, although the yield increase was not as large as for fallow.

Either late fall or early spring seeding consistently had higher water use efficiency compared to late spring seeding. Recording high water use efficiency by fall seeding, in spite of a tendency to use less water, suggests that evaporation component of the total water use was probably reduced by fall seeding. In addition, lower temperatures during the growing season might have improved physiological efficiency by reducing transpiration and maintenance respiration for fall and early spring seeding compared to late fall seeding. Fall and early spring seeding were also more efficient in converting biomass into grain yield as seen from higher harvest index in 2000 (Table 1.3 and 1.4). Reduced plant height and prolonged reproductive growth stage with fall seeding (Kirkland and Johnson 2000) might also be contributing to higher water use efficiency.

1.4 Summary

Fall and early seeding dates can improve the sustainability of canola and mustard production in the stress prone semiarid prairie. Pooled over the three contrasting environments (years), early spring seeding and fall seeding increased seed yield over late spring seeding by 53% and 36% in the fallow phase and 82% and 31% in the stubble phase, respectively. Reduced plant stand with alternative seeding dates had no effect on biomass production and seed yield. All canola and mustard species responded similarly to seeding dates. Although fall seeding reduced water use in some cases, the efficiency of water use increased with fall and early spring compared to late spring seeding. Since, the year 2001 was extremely dry resulting in differing crop responses compared to results for 1999 and 2000, we recommend this study to be repeated for one more normal or slightly dry year to solidify recommendations to producers.

Acknowledgement

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Table 1.1 Growth, water use and yield of different Brassica species on fallow in response to seeding dates in 1999 at Swift Current.

Cultivars	Population (m^{-2})	Water Use (mm)	Biomass (kg ha^{-1})	Seed Yield (kg ha^{-1})	HI	WUE (kg ha^{-1} mm^{-1})
Cultivars*						
Arrow	138b	39.9a	5720b	1943a	0.34a	4.9 a
Cutlass	180a	40.1a	7093a	2014a	0.30a	5.0 a
CQ1	135b	40.0a	5743b	1805a	0.32a	4.5 a
Sunbeam	146b	38.4a	5806b	1825a	0.32a	4.7 a
Seeding						
Fall	94c	38.6a	6357a	2052a	0.33a	5.3a
Early	195a	40.1a	7057a	2178a	0.32a	5.4a
Late	162b	40.2a	4858b	1461b	0.31a	3.6b

* All four cultivars were used in the statistical analysis.

Table 1.2 Growth, water use and yield of different Brassica species on stubble in response to seeding dates in 1999 at Swift Current.

Cultivars*	Population (m^{-2})	Water Use (mm)	Biomass (kg ha^{-1})	Seed Yield (kg ha^{-1})	HI	WUE (kg ha^{-1} mm^{-1})
Cultivars						
Arrow	103a	34.1a	4727a	1427a	0.31a	4.3a
Cutlass	122a	33.8a	5700a	1533a	0.28a	4.5a
CQ1	109a	34.4a	4531a	1351a	0.31a	4.0a
Sunbeam	109a	32.9a	5116a	1166a	0.23a	3.5a
Seeding						
Fall	89a	33.1a	5198a	1430a	0.28a	4.3a
Early	98a	33.9a	5967a	1574a	0.27a	4.6a
Late	145a	34.3a	3891b	1104b	0.30a	3.2b

* All four cultivars were used in the statistical analysis.

Table 1.3 Growth, water use and yield of different Brassica species on fallow in response to seeding dates in 2000 at Swift Current.

Cultivars	Population (m^{-2})	Water Use (cm)	Biomass (kg ha^{-1})	Seed Yield (kg ha^{-1})	HI	WUE (kg ha^{-1} mm^{-1})
Cultivars*						
Arrow	103a	35.5a	10115a	1789a	0.18b	5.03ab
Cutlass	119a	36.2a	9126a	1918a	0.23a	5.33a
Pennant	95a	36.0a	8318a	1440c	0.17b	4.01c
Sunbeam	100a	34.1a	8797a	1621b	0.18b	4.76b
Seeding						
Fall	83b	34.7a	9513ab	2045a	0.23a	5.88a
Early	95b	36.2a	9721a	1868b	0.19b	5.19b
Late	134a	35.5a	8033b	1162c	0.15c	3.28c

* All four cultivars were used in the statistical analysis.

Table 1.4 Growth, water use and yield of different Brassica species on stubble in response to seeding dates in 2000 at Swift Current.

Cultivars*	Population (m^{-2})	Water Use (mm)	Biomass (kg ha^{-1})	Seed Yield (kg ha^{-1})	HI	WUE (kg ha^{-1} mm^{-1})
Cultivars						
Arrow	114a	34.1ab	4645ab	801a	0.15a	2.28ab
Cutlass	121a	36.5a	5694a	916a	0.16a	2.45a
Pennant	101a	35.9a	4135b	702a	0.17a	1.81b
Sunbeam	100a	31.3b	4790ab	783a	0.17a	2.55a
Seeding						
Fall	100a	29.3b	4132b	747b	0.18a	2.60b
Early	106a	37.7a	6714a	1196a	0.18a	3.34a
Late	122a	36.6a	3603b	458c	0.13b	1.21c

* All four cultivars were used in statistical analysis.

Table 1.5 Growth, water use and yield of different Brassica species on fallow in response to seeding dates in 2001 at Swift Current.

Cultivars	Water Use (cm)	Biomass (kg ha^{-1})	Seed Yield (kg ha^{-1})	HI	WUE ($\text{kg ha}^{-1}\,\text{mm}^{-1}$)
Cultivars*					
Arrow	24.3a	4835a	640a	0.23a	3.40a
Cutlass	24.5a	5031a	734a	0.18a	2.62a
Pennant	25.4a	4996a	724a	0.17a	2.85a
Sunbeam	23.4a	4246a	544a	0.16a	2.28a
Seeding					
Fall	23.6a	-	426b	-	1.76b
Early	25.3a	6018a	965a	0.16b	3.87a
Late	24.4a	3399b	738a	0.22a	2.73b

* All four cultivars were used in the statistical analysis.

Table 1.6 Growth, water use and yield of different Brassica species on stubble in response to seeding dates in 2001 at Swift Current.

Cultivars	Water Use (cm)	Biomass (kg ha^{-1})	Seed Yield (kg ha^{-1})	HI	WUE ($\text{kg ha}^{-1}\,\text{mm}^{-1}$)
Cultivars					
Arrow	15.5a	1490a	80c	0.05d	0.53c
Cutlass	15.6a	1178a	214a	0.18a	1.38a
Pennant	15.7a	1248a	151b	0.12c	0.96b
Sunbeam	15.4a	1331a	182ab	0.14b	1.22ab
Seeding					
Fall	15.3a	1378a	143b	0.10c	0.94ab
Early	15.6a	1252a	144b	0.12b	0.93b
Late	15.7a	1305a	185a	0.14a	1.19a

* All four cultivars were used in the statistical analysis.

Table 1.7 Seed yield (kg ha^{-1}) of different Brassica species on fallow in response to seeding dates at Swift Current.

			Cultivars		
Seeding	Arrow	Cutlass	CQ1/Pennant *	Sunbeam	Mean
			1998-1999		
Fall	2200	2093	1911	2002	2099a
Early Spring	2229	2363	1938	2181	2258a
Late Spring	1400	1587	1567	1291	1426b
Mean	1943a	2014a	1805	1825a	
			1999-2000		
Fall	2069	2357	1747	2007	2144a
Early Spring	2083	2066	1656	1668	1939b
Late Spring	1215	1330	916	1187	1244c
Mean	1789a	1918a	1440	1621b	
			2000-2001		
Fall	48	736	509	410	398b
Early Spring	1717	570	764	581	1032a
Late Spring	515	977	898	642	711b
Mean	640a	734a	724	544a	
			Mean		
Fall	1439	1729	-	1473	1547b
Early Spring	2046	1666	-	1476	1743a
Late Spring	1043	1338	-	1040	1140c
Mean	1523a	1578a	-	1330b	

* Canola quality mustard line was replaced with Pennant Yellow mustard in 2000 and 2001. For analysis both genotypes are excluded.

Table 1.8 Seed yield (kg ha^{-1}) of different Brassica species on stubble in response to seeding dates at Swift Current.

	Cultivars				
Seeding	Arrow	Cutlass	CQ1/Pennant *	Sunbeam	Mean
		1998-1999			
Fall	1600	1497	1605	1018	1372ab
Early Spring	1757	1779	1311	1449	1662a
Late Spring	923	1322	1136	1032	1093b
Mean	1427ab	1533a	-	1166b	
		1999-2000			
Fall	744	774	776	694	737b
Early Spring	1302	1397	845	1241	1314a
Late Spring	357	577	484	413	449c
Mean	801a	916a	702	783a	
		2000-2001			
Fall	30	212	128	201	148a
Early Spring	136	199	112	129	155a
Late Spring	75	232	214	217	175a
Mean	80b	214a	151	182a	
		Mean			
Fall	791	827	-	638	752b
Early Spring	1065	1125	-	940	1043a
Late Spring	452	711	-	554	572c
Mean	769b	888a	-	710b	

* Canola quality mustard line was replaced with Pennant yellow mustard in 2000. For analysis both genotypes are excluded.

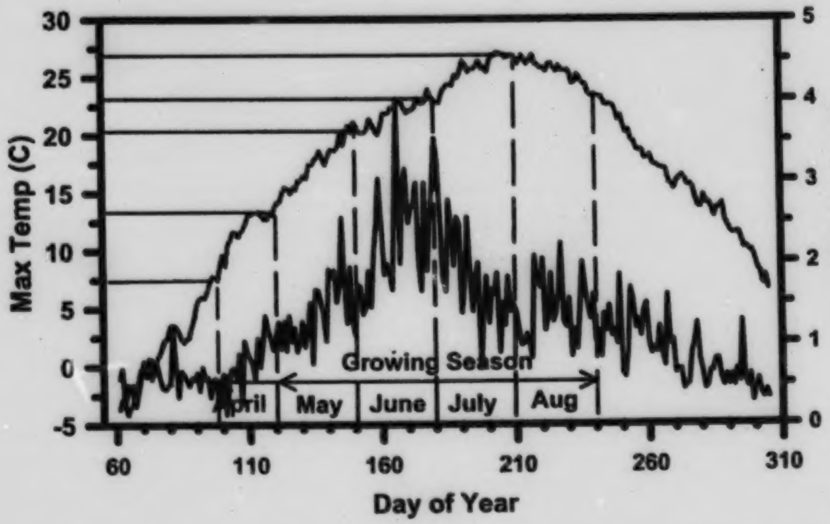

Fig. 1.1 Extending growing season with fall seeding. Long term maximum daily temperature and rain fall are presented for comparing actual growing season with extended growth period.

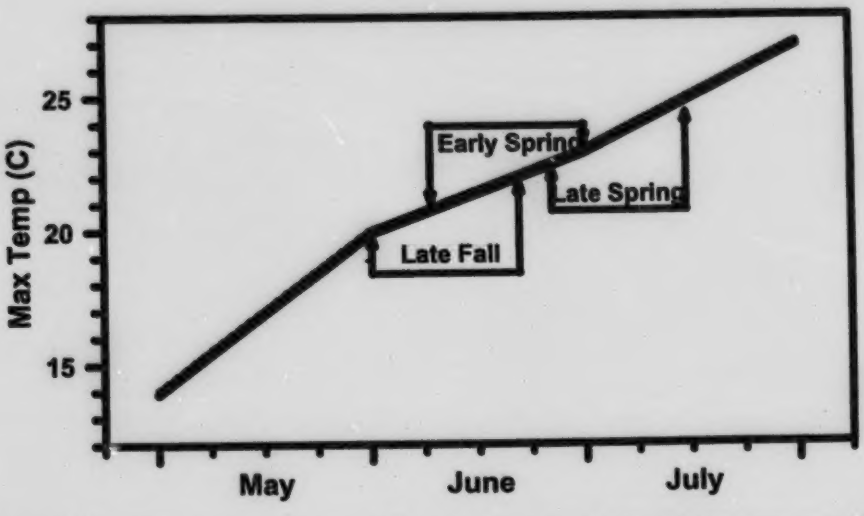

Fig. 1.2 Long term maximum daily temperature for Swift Current area that coincides with the flowering of canola seeded on different seeing dates

CHAPTER 2

Stubble and Seeding Management to Improve Microclimate and Seed Yield of Canola

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Abstract

Standing stubble traps snow and creates a favorable microclimate which increased yields in wheat and pulses. Generally, the taller the stubble the greater is the effect on microclimate and yield. Alternate seeding dates such as late fall or early spring seeding may have an effect on stubble microclimate and canola productivity. A field study using farm scale seeding and harvesting equipments was conducted over three seasons (fall 1998 to summer 2001) to assess the effect of stubble management on the microclimate, water use and seed yield of canola at Swift Current. Tall (>30 cm), short (15 cm) and cultivated treatments were imposed in fall and in spring. An additional tall stubble treatment with extra fertilizer N was included to assess the role of fertilizer in canola response to seeding and stubble management practices. Canola cv. 'Arrow' was seeded in late fall (before freeze-up), early spring (last week of April) and late spring (third week of May). The differences in wind velocity, soil temperature and solar radiation reaching the soil surface indicate significant modification of the microclimate by tall compared to cultivated stubble. Seeding dates influenced plant population significantly, while the effect of stubble management was small and non significant. Stubble management did not influence biomass production and water use. But tall stubble and tall stubble+extra fertilizer significantly increased seed yield by 21 and 39%, respectively, over the spring cultivated stubble treatment. Both improved microclimate and improved water use efficiency were cumulatively responsible for the higher yield potential of tall compared to cultivated stubble. Seeding dates interacted with stubble treatments. Thus tall stubble has potential to increase canola yields in the heat and water stressed semiarid prairie.

2.1 Introduction

The growing season on the Canadian prairie is short and crops are subjected to increasing temperature stress and precipitation deficit during the season. The deficit between water supply and the potential evapotranspiration increases through the growing season in this region. Crop productivity is directly proportional to the amount of water transpired. Transpiration can be increased either by increasing water supply or by reducing evaporation. Therefore, any practice that improves water available for transpiration either by conserving or by reducing evaporation, increases crop yield.

Standing stubble increases snow trapping compared to conventional fallow (Lafond et al. 1992). The amount of snow trapped is directly proportional to stubble height (Aase and Siddoway 1980; McConkey et al. 1997; Steppuhn 1994). Therefore, the practice of using taller standing stubble increases the water supply to the crops.

Tall standing stubble reduces wind speed, solar radiation reaching the soil surface and maintains soil temperature cooler than fallow (Cutforth and McConkey 1997). The altered energy balance reduced water lost by evaporation. The major changes in microclimate are noticed early in the growing season, when the crop canopies are small and cannot regulate evaporation loss on their own.

The microclimate also has direct effects on the crop (Aase and Siddoway 1980; Cutforth and McConkey 1997). Compared to cultivated stubble, there are several reasons why evaporation of water from tall stubble treatments is reduced , two of which are reduced turbulent air mixing due to reduced wind velocity and reduced solar radiation. However, while evaporation is reduced, plant photosynthesis is not. Greater biomass accumulation in tall stubble compared to cultivated/fallow plots has been reported (Aase and Siddoway 1980; Cutforth and McConkey 1997). Compared to cultivated stubble treatments, the cumulative result of all microclimatic alterations by tall stubble was increased yield in wheat and pulses at Swift Current. No information is available on the benefit of tall stubble for canola. Therefore, a large scale field trial was planned with the following objectives:

1. To study the effect of stubble management on microclimate under a canola canopy.
2. To determine the stubble management effect on canola yield and water use efficiency.
3. To determine the effect of seeding date on canola response to stubble management.

2.2 Materials and Methods

A field study was conducted on a Swinton loam soil (Orthic Brown Chernozem) (Ayres et al. 1985) at the Agriculture and Agri-Food Canada, Semiarid Prairie Agricultural Research Centre (SPARC), Swift Current for three seasons (1998-1999, 1999-2000 and 2000-2001). The main and subplot sizes were 45m X 45m and 15m X 45m, respectively. A Glyphosate tolerant Argentine canola cv. 'Arrow' was seeded with a Flexicoil 5000 Air seeder with Flexi-Coil "Stealth" knives (Flexi-Coil Ltd, Saskatoon, SK, S7K 3S5) at 23-cm row spacing. A seeding rate of 9.5 kg ha^{-1} was used to attain an acceptable stand of both fall and spring seeded crops. Fertilizer rate was 84 kg N ha^{-1} , 22 kg P ha^{-1} and 22 kg S ha^{-1}, of which 78 kg N and all of S was broadcasted in the spring and the remaining N and all P was mid row banded at seeding. Post emergent Glyphosate applications kept the experimental area weed free.

Seeding dates and stubble management combinations were compared for their effect on canola production. Seeding dates were late fall (27 October to 6 November; just before freeze-up), early spring (24 to 25 April) and late spring (19 to 25 May). Three stubble heights (Tall, ≥12"; Short, 6"; and cultivated) were established in the fall as well as in the spring, along with a tall stubble treatment with extra fertilizer (34 kg ha^{-1} extra N) were used in stubble management. Stubble treatments were imposed on wheat grown on fallow, which was harvested using a header equipped combine to leave stubble taller than 30 cm. Out of six treatment plots, four overwintered as tall stubble. The fall cultivated plot was slowly (<5 km h^{-1}) worked with a tandem disc followed by harrow-packers. About one-half of the standing stubble was buried with the remaining residue lying flat on the soil surface. The short stubble (15 cm high) in fall was deployed by cutting the tall stubble with an haybine without windrowing. In the following spring, spring cultivated and short stubble in spring plots were deployed on plots that had overwintered as tall stubble. One of the remaining two tall stubble plots received an additional 34 kg ha^{-1} N in the spring.

The microclimate measurements were restricted to the early spring seeded plots of tall, short stubble (spring) and cultivated (spring) plots in the randomly selected replication. Soil temperatures were measured with thermistors at 0.05, 0.10 and 0.30 m depths. Air temperatures were measured with double shielded and passively aerated copper-constantan thermocouples at 0.15, 0.50 and 1.00 m above ground. Wind velocity at 0.15, 0.50, 1.00 and 2.00 m above surface was measured with anemometers (Wind Sentry and Gill 3 Cup anemometers, RM Young Company, Traverse City, MI). Solar radiation above the canopy (only in one plot) and solar radiation reaching the soil surface (approximately 7cm above the ground) were measured using 1 m long tube solarimeters ("Monteith pattern" tube solarimeter, Delta-T Devices Ltd. Cambridge, UK). Temperature measurements were replicated at 3 to 4 locations within the plot. Wind velocity and solar radiation readings were made at only one place.

Plant population was counted after the emergence of each seeding date. A row length of 1.82 m from each quarter (i.e. 4 replications per plot) was used for plant counts. Soil water was measured gravimetrically before seeding and after harvest to a depth of 1.20m. Consumptive water use was calculated as the difference between spring and fall soil moisture plus the precipitation received between those dates. Before harvest, 1.82 m row lengths from each quarter were hand harvested to measure biomass production and harvest index. Seed yields were measured with a full-size MF 550 combine (AGCO Corporation, 4205 River Green Parkway, Duluth, GA 30096) after windrowing; the middle swath in each plot (5.5m X 18m) was used for seed yield estimation. Water use efficiency was calculated as the amount of water used to produce a unit of seed.

The three seasons of this study varied drastically. Therefore, we analyzed the response of canola to stubble and seeding management for each environment (year) separately. Therefore, analysis of variance was conducted for each agronomic parameter using the strip plot design (Gomez and Gomez 1995) for each year separately. However, the mean seed yield across three years was analyzed separately to generalize the results. The GLM procedure of SAS (SAS Institute 1985) was used for the analysis. For comparing diurnal trends, three five day intervals were selected and mean of them were presented. Two of those intervals were before the crop canopy masked the stubble management effect, while the third was late in the season when most of the stubble management effects might have been masked by the crop canopy.

2.3 Results and Discussion

2.3.1 Microclimate

Among the microclimatic parameters measured, soil temperature at 5 cm depth, wind velocity at 15 cm height and solar radiation at ground level were significantly influenced by stubble height. Therefore, diurnal trends over three intervals during the growing season (Fig. 2.1 to 2.3) and seasonal trends (Fig. 2.4 to 2.6) for only those three parameters are presented. The previous results indicate that the above parameters may have the greatest effect on transpiration, evaporation and water use efficiency (Cutforth and McConkey 1997).

Diurnal trends in soil temperature indicated higher temperature under cultivated conditions in all three stages of crop growth (Fig 2.1 to 2.3). The curves were typical for all three years. Similar soil temperature differences for different stubble treatments has been observed in previous studies (Aase and Siddoway 1980, Cutforth and McConkey 1997). Throughout the growing season, soil temperature in short stubble behaved similar to soil temperature in tall stubble. Previous studies also found similar trends between stubble height treatments early in the growing season (Cutforth and McConkey 1997). In short stubble treatment relatively more stubble was lying prostrate on the ground. Aase and Siddoway (1980) observed 19% higher reflected radiation in short compared to cultivated stubble plots in early spring, which was higher than that for tall stubble. Thus, the greater albedo for the short stubble treatment might have contributed to the lower soil temperatures in short stubble compared to tall stubble early in the season.

The plots of diurnal trends in horizontal wind speed show the huge effect stubble management has on wind speed near the soil surface. Early in the growing season (11-15, 16-

20 and 21-25 days after seeding), wind speed in the cultivated plots was 4 to 11 times higher compared to wind speed in tall stubble plots (Fig. 2.1 to 2.3). Generally, the effect of short stubble on wind speed was intermediate to the effects of cultivated and tall stubble (16-20 days after seeding in 2000) (Fig. 2.2). Similar findings have been reported by Cutforth and McConkey (1997). Wind speed in tall stubble was lowest during the coolest parts of the day (i.e., at night between 2200 to 0700 h), while wind speeds in the cultivated plot remained much higher, such that the highest ratios of cultivated to tall wind speeds occurred during this time. Diurnal cycles were less evident later in the growing season with the cyclical pattern in wind speed generally disappearing after flowering (66-70 days after seeding).

Less solar radiation reached the soil surface in the tall stubble compared to cultivated stubble plots, especially in the middle of the day (Fig 2.1 to 2.3). The difference tended to be small in the beginning of the season, increasing to a maximum and then decreasing again as the season progressed. Early in the season, when the canola seedlings were small and close to the soil surface, the entire difference in solar radiation penetration to 7 cm above the soil surface (sensor height) was due to the differences in standing stubble (Cutforth and McConkey 1997). However, visual observations suggests that the seedling grew taller more quickly and appeared to be bushier in the tall stubble compared to cultivated stubble plot, thus the differences between radiation interception and/or penetration into the canopy. Aase and Siddoway (1980) also found that early growth was greater in tall compared to cultivated stubble plots. The differences in radiation interception and wind velocity were higher during the middle of the day, when they would have maximum effect on evaporation.

Seasonal trends of the effect of stubble height on soil temperature, wind velocity and solar radiation were similar to the effect of stubble height on the diurnal trends (Fig 2.4 to 2.6). Warmer soil in the cultivated stubble compared to tall stubble was observed through out the season. Even after full canopy cover, stubble height continued to have an effect on soil temperature. Both seasonal and diurnal temperature graphs show that the soil temperature range was greater for cultivated compared to tall stubble plots. For example, in 2000, between 8 to 18 June (159 to 169 Julian day) the soil temperature range for cultivated stubble plots was 5.3 °C, but was only 4.4 °C for the tall stubble. This greater fluctuation in temperature in the sub-optimal range can subject plants to greater stress. Canopy development was similar in 1999 and 2000 and the good canopy development caused the stubble height effects on wind speed at 15 cm height to disappear well before flowering (Fig. 2.4 and 2.5). However, 2001 was extremely dry and canopy development was very poor. Therefore, the stubble management effect on wind velocity was greater and was observed for a longer period in 2001 compared to other years (Compare Fig. 2.6 to 2.4 and 2.5). These annual differences in canopy development affected solar radiation interception in a manner similar to wind velocity. Thus, stubble management had a large effect on diurnal and seasonal microclimate in canola.

2.3.2 Effect on Crop Growth and Yield

Compared to stubble management, seeding management had a greater influence on crop establishment. In general, fall seeding reduced plant populations in 1999 and 2000 compared to early or late spring seeding. However, 2001 was the second driest and the fifth warmest year in the recorded history of Swift Current (1885 to 2001) (Judiesch and Cutforth

2002) with the result that crop establishment was very poor. Population for the fall seeded canola was almost zero (data not presented). Although, the effect of stubble management on crop establishment was not significant, fall seeding into tall standing stubble appeared to result in improved crop establishment compared to cultivated stubble plots, especially in years when crusting was a problem. Better moderation of the microclimate by tall compared to cultivated stubble reduced soil evaporation and improved seed bed soil moisture conditions, which might be responsible for the better crop establishment in tall stubble. Similar suggestions have been made by Aase and Siddoway (1980).

Environment had a significant effect on water use, but water use was not affected by stubble management or seeding date. Stubble height increases snow trapping by preventing wind removal of snow (Lefond et al. 1992; Stephun 1994). All three winters during the present study received very little snow fall and year 1999 and 2000 received good rainfall in the early part of the season (Table 2.1). Therefore, stubble management had no significant effect on water use.

For 1999 and 2000, years with average to above average rainfall amounts and good distribution throughout the growing season, biomass production was dependent upon seeding date with fall seeding producing the most biomass and the late spring seeding the least biomass (Table 2.2 and 2.3). For 2001, a drought year with an extremely dry winter and severely drought early in the growing season, the early spring seeding date produced the most biomass and fall seeding the least biomass. The distribution of the sparse rainfall was very critical in biomass (and grain yield) production in 2001. Sparse rainfall during critical growth periods for the early spring seeded canola promoting production prior to the hot weather later in the season. The rainfall too late for the fall seeded canola, occurring during less critical growth periods resulting in low biomass production. Critical growth period for the late spring seeded canola occurred during hot, dry windy periods that also reduced biomass production.

Stubble management had significant effect on biomass production only in 2000 and tall stubble accumulated more biomass than cultivated plots in 2000. Comparing across all 3 years, tall stubble plots tended to produce the most biomass, especially when extra fertilizer was applied. A previous study has indicated that canola and mustard can respond to higher levels of N under favourable moisture conditions (Miller et al. 2002). Tall stubble has been found to reduce evaporation (Cutforth and McConkey 1997). Thus, the little bit extra moisture conserved for transpiration might have increased fertilizer N use efficiently. These results suggest that for optimum production of canola in the semiarid prairie, fertilizer rates similar to those of the Black soil zone should be applied.

Similar to biomass and water use, seed yield was greatly influenced by environment (Table 2.5). As well, stubble management and seeding management also affected grain yield. Pooled over the three years, tall stubble and tall+fertilizer treatments produced 21 and 39% higher seed yield compared to the fall cultivated plots. Short stubble plots were statistically similar to tall stubble plots, but lower than tall+fertilizer plots. Seed yield gains in tall+fertilizer treatments were accompanied by higher water use efficiencies (Table 2.2 and 2.4). Thus, reduced evaporation and the improved microclimate enabled canola to use the extra available nitrogen to produce highest yields.

In 1999 and 2000, when good rainfall amount and distribution during the growing season occurred, fall seeding produced significantly higher yields compared to early and later spring seeding dates. Thus, seeding management is a useful technology in the semiarid prairie to avoid the poor yields associated with mid-May seeding of canola. However, in the date of seeding study, fall seeding did not produce the highest seed yield but early spring seeding (especially under stubble) did produce the highest seed yield. This suggests that stubble management practices to maintain stubble height such as tall stubble and tall stubble+ fertilizer were responsible for over all yield increase by fall seeding. Early in the spring, standing tall stubble does not allow the soil to cool to the same extent as bare soil (Aase and Siddoway 1980). Thus, tall stubble on the soil surface promotes warmer soils in the winter and earlier spring thaw than cultivated stubble plots (Sharratt 2002). Earlier spring thaw would favour earlier emergence of canola, similar to the early greening of winter wheat (Aase and Siddoway 1980). In addition, the improved microclimate would support better canola growth, especially during the seedling and flowering stages (Cutforth and McConkey 1997; Sharratt 2002b). Thus, in the present trial tall and/or tall plus extra fertilizer treatments were responding much better to fall seeding crop (50 to 87% higher seed yield compared to spring cultivated and late spring seeded plot) than to early spring and late spring seeding (28 to 82% and 10 to 21%, respectively) (Table 2.5). In 2001, an extremely dry year, yields were greatest for the early spring seeding date and least for the fall seeding date. The distribution of precipitation was a major factor determining the yield response to seeding date. Rains occurred too late in the growing season to help the fall seeded crop, the late spring seeded canola developed during hot, dry and windy weather reduced seed yield. The rainfall distribution, temperature during flowering were least stressful for the early spring seeded canola, which responded by producing the most grain in 2001. Therefore, data from one more typical year is needed to make strong recommendations.

2.4 Summary

Tall stubble positively modified the microclimate within the canola canopy. Both diurnal and seasonal trends in soil temperature at 5 cm depth, wind velocity at 15 cm above the soil surface and solar radiation interception near the soil surface were significantly modified by stubble management. Both stubble height and seeding date improved seed yield significantly by improving the water use efficiency of a limited water supply. Generally fall and early spring seeding of canola (which were not different) increased yields by 27% over late spring seeding, and tall stubble increased grain yield of canola by 25% over cultivated stubble seeded canola. Because of the extremely dry 2001, which was an atypical drought year for the semiarid prairie, we recommend one more year of data be collected and analyzed in conjunction with 1999, 2000 and 2001 to improve the recommendations that will be passed on to the producers.

Acknowledgment

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Table 2.1 Average monthly air temperatures and precipitation for the growing season (May through August) 1999 and 2000, as well as the long-term mean monthly mean air temperature and precipitation total.

Month	T_{max} (°C)				T_{min} (°C)				Precipitation (mm)			
	1999	2000	2001	Mean†	1999	2000	2001	Mean	1999	2000	2001	Mean
May	15.4	17.5	19.8	17.8	4.4	4.3	4.5	4.0	93.9	65.3	22.6	43.9
June	19.4	19.8	21.0	22.1	8.9	8.0	9.0	8.7	86.2	54.0	31.8	72.2
July	22.7	25.3	26.5	26.0	10.2	13.0	12.9	11.2	60.3	127.0	63.0	52.4
August	26.0	25.7	29.0	25.2	11.7	11.3	12.4	10.0	16.8	13.1	3.2	42.4

† Long-term mean (1885 to 2001)

Table 2.2 Population, water use, biomass, seed yield, water use efficiency (WUE), and harvest index of Argentine canola in 1999 at Swift Current.

Treatments	Population (m^{-2})	Water Use (cm)	Biomass (kg ha^{-1})	Seed Yield (kg ha^{-1})	HI	WUE (kg ha^{-1} mm^{-1})
Stubble						
Tall Stubble	100a	35.6a	6670a	2265a	0.35a	6.4ab
Tall+Fertilizer	101a	33.9a	7226a	2360a	0.32a	7.0a
Short (Fall)	95a	33.9a	6772a	1917b	0.29a	5.7bc
Short (Spring)	92a	35.8a	6814a	2063ab	0.31a	5.8bc
Cultivated (Fall)	89a	36.5a	6459a	1794b	0.29a	4.9c
Cultivated (Spring)	105a	35.4a	6008a	1754b	0.30a	5.0c
Seeding						
Fall	56c	35.3a	7835a	2370a	0.30a	6.8a
Early Spring	94b	34.8a	7106b	1983b	0.35a	5.7b
Late Spring	132a	35.5a	5339c	1826b	0.28a	5.2b

Table 2.3 Population, water use, biomass, seed yield, water use efficiency (WUE), and harvest index of Argentine canola in 2000 at Swift Current.

Treatments	Population (m^{-2})	Water Use (cm)	Biomass (kg ha^{-1})	Seed Yield (kg ha^{-1})	HI	WUE (kg ha^{-1} mm^{-1})
Stubble						
Tall Stubble	88a	26.9a	6616b	1449bc	0.22a	5.40a
Tall+Fertilizer	89a	28.6a	8039a	1805a	0.23a	6.29a
Short (Fall)	89a	27.6a	6296bc	1489b	0.24a	5.40a
Short (Spring)	89a	27.1a	5876bc	1438bcd	0.25a	5.34a
Cultivated (Fall)	90a	24.6a	5735c	1323cd	0.24a	5.40a
Cultivated (Spring)	94a	26.0a	5476c	1280d	0.24a	5.86a
Seeding						
Fall	57c	27.5a	8015a	1756a	0.22b	6.33a
Early Spring	137a	26.5a	6042b	1578b	0.26a	5.97a
Late Spring	76b	26.5a	5385c	1138c	0.22b	4.29b

Table 2.4 Water use, biomass, seed yield, water use efficiency (WUE), and harvest index of Argentine canola in 2001 at Swift Current.

Treatments	Water Use (cm)	Biomass (kg ha^{-1})	Seed Yield (kg ha^{-1})	HI	WUE (kg ha^{-1} mm^{-1})
Stubble					
Tall Stubble	15.3a	2698a	446b	0.15ab	2.85ab
Tall+Fertilizer	15.6a	3074a	614a	0.20a	3.90a
Short (Fall)	14.8a	2160a	378b	0.16ab	2.46b
Short (Spring)	13.7a	2605a	438b	0.16ab	3.26ab
Cultivated (Fall)	14.3a	2400a	318c	0.12b	2.23b
Cultivated (Spring)	14.2a	2951a	663a	0.14b	3.17ab
Seeding					
Fall	13.3b	2114b	204c	0.09b	1.42c
Early Spring	15.5a	3451a	723a	0.21a	4.66a
Late Spring	15.2a	2378b	426b	0.17a	2.85b

Table 2.5 Effect of stubble and seeding management on seed yield of Argentine canola (cv. Arrow) from 1999 to 2001 at Swift Current.

Treatments	Seeding			
	Late Fall	Early Spring	Late Spring	Mean
		1998-1999		
Tall Stubble	2741	2177	1877	2265a
Tall+Fertilizer	2677	2452	1950	2360a
Short (Fall)	2195	1795	1760	1917b
Short (Spring)	2400	1948	1840	2063ab
Cultivated (Fall)	1835	1713	1833	1794b
Cultivated (Spring)	-	1812	1696	1754b
Mean	2370a	1983b	1826b	
		1999-2000		
Tall Stubble	1660	1469	1219	1449bc
Tall+Fertilizer	2069	2013	1333	1805a
Short (Fall)	1708	1559	1200	1489b
Short (Spring)	1679	1608	1026	1438bcd
Cultivated (Fall)	1665	1360	943	1323cd
Cultivated (Spring)	-	1455	1106	1281d
Mean	1756a	1577b	1138c	
		2000-2001		
Tall Stubble	162	730	446	446b
Tall+Fertilizer	301	828	714	614a
Short (Fall)	134	716	285	378b
Short (Spring)	281	616	417	438b
Cultivated (Fall)	140	573	241	318b
Cultivated (Spring)	-	872	455	663a
Mean	204c	723a	426b	
		Mean		
Tall Stubble	1521	1459	1181	1387b
Tall+Fertilizer	1682	1764	1332	1593a
Short (Fall)	1346	1357	1082	1261bcd
Short (Spring)	1453	1391	1094	1313bc
Cultivated (Fall)	1213	1215	1006	1145d
Cultivated (Spring)	-	1380	1086	1233cd
Mean	1443a	1428a	1130b	

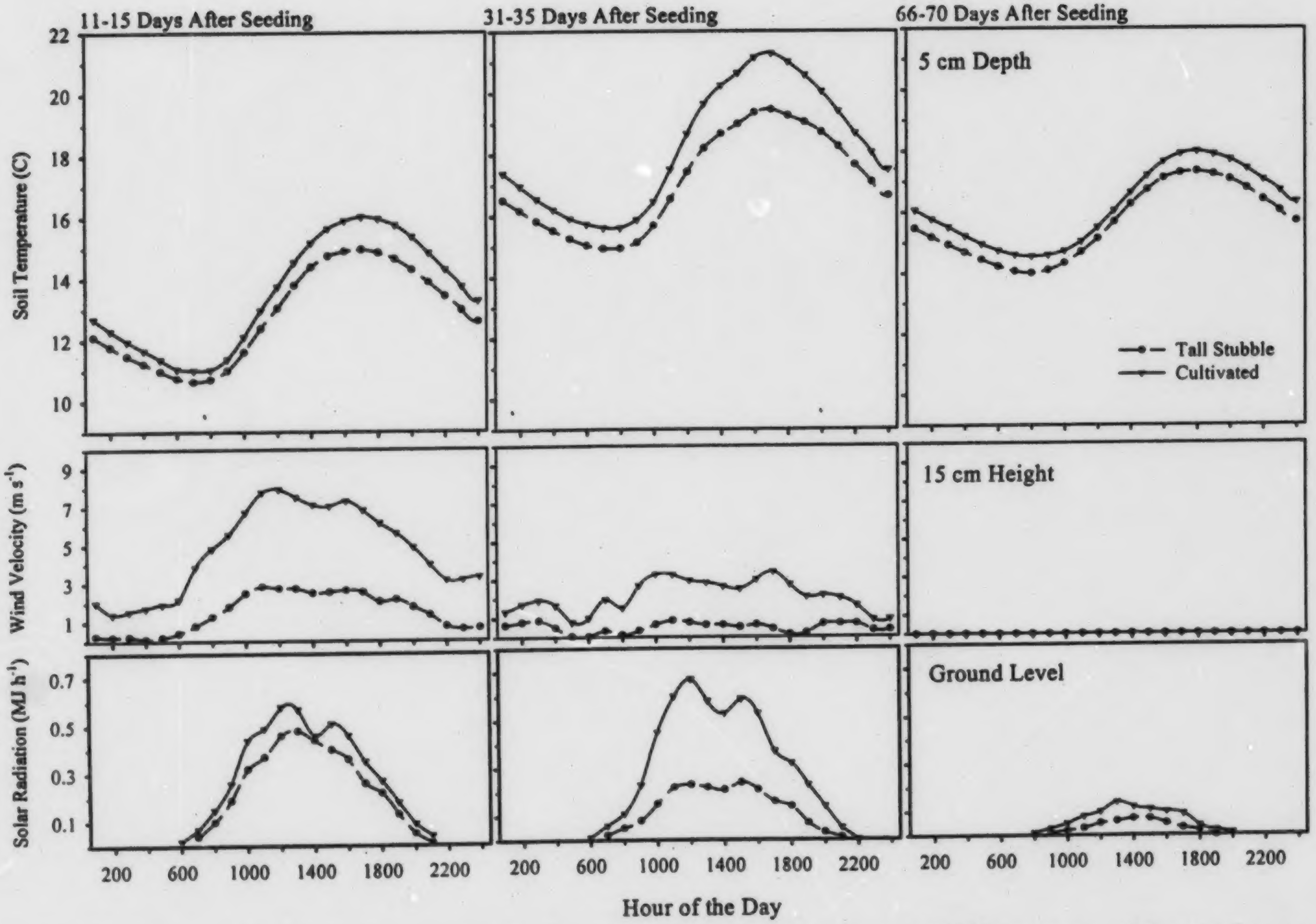

Figure 2.1 Effect of stubble management on the diurnal trend of the microclimate at different stages of the canola crop at Swift Current in 1999. Diurnal trends are the means of five days for each period.

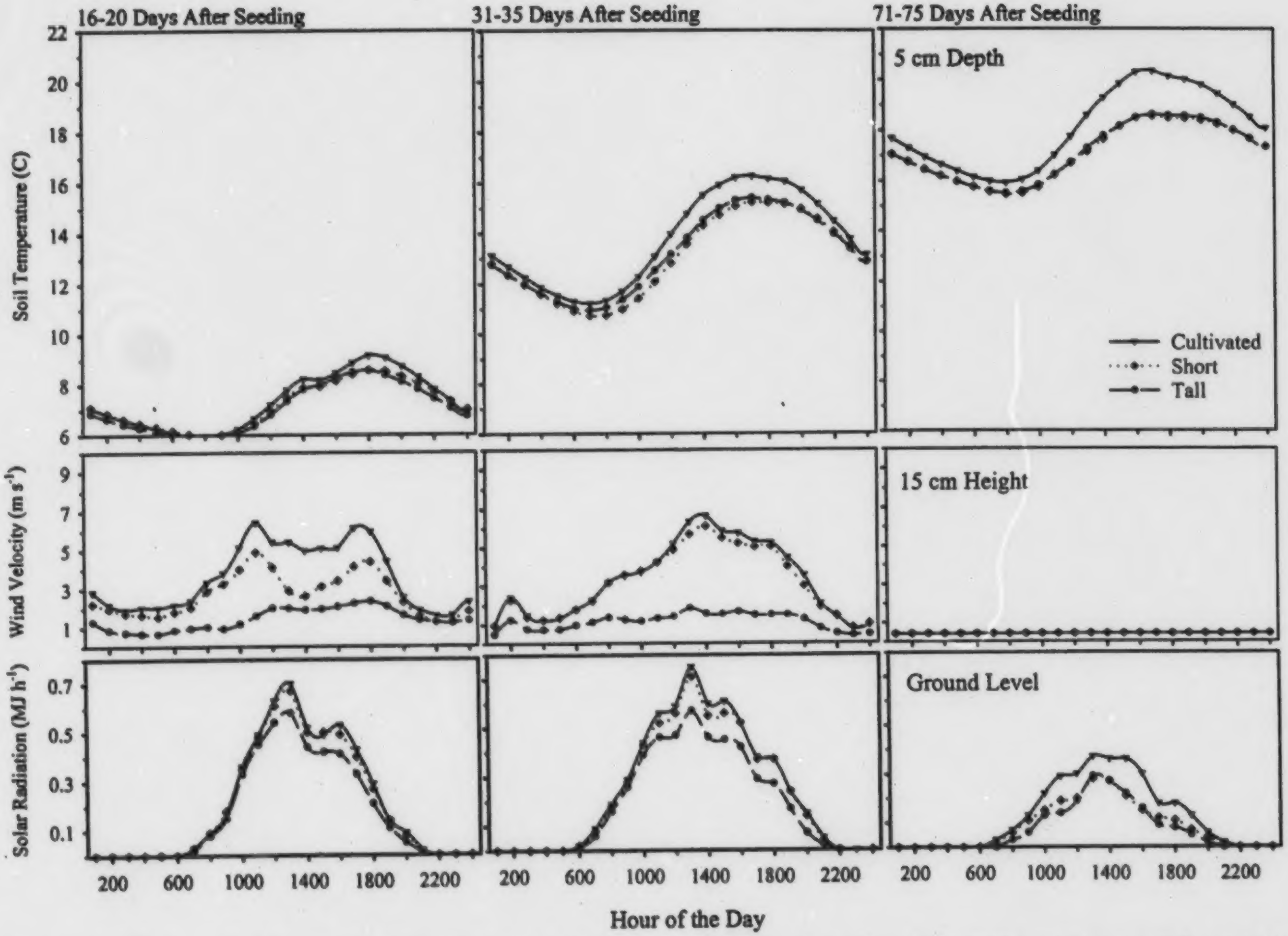

Figure 2.2 Effect of stubble microclimate on the diurnal trend of the microclimate at different stages of the canola crop at Swift Current in 2000. Diurnal trends are the means of five days for each period.

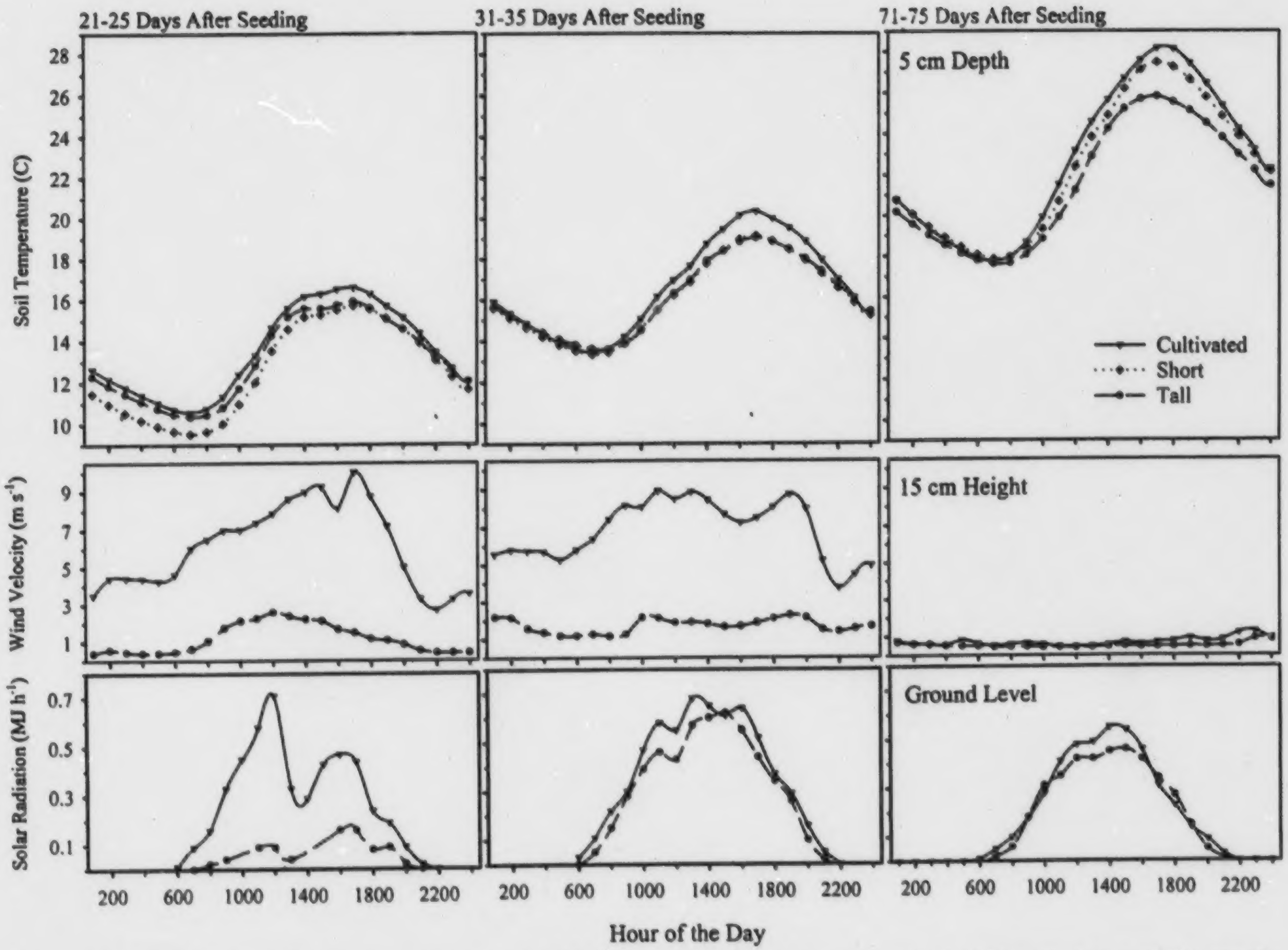

Figure 2.3 Effect of stubble management on the diurnal trend of the microclimate at different stages of the canola crop at Swift Current in 2001. Diurnal trends are the of five days for each period.

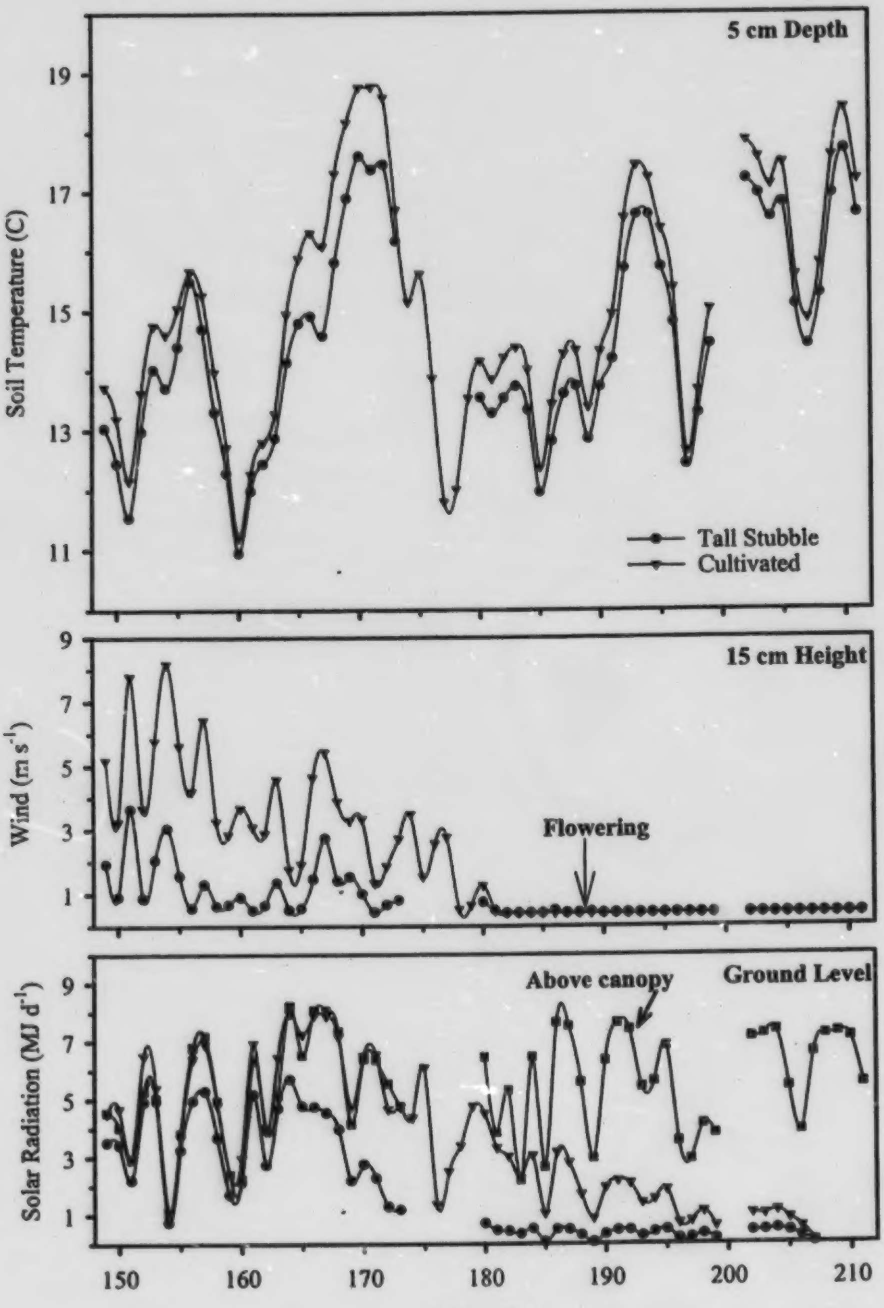

Figure 2.4 Effect of stubble management on the seasonal microclimate of the canola crop at Swift Current in 1999.

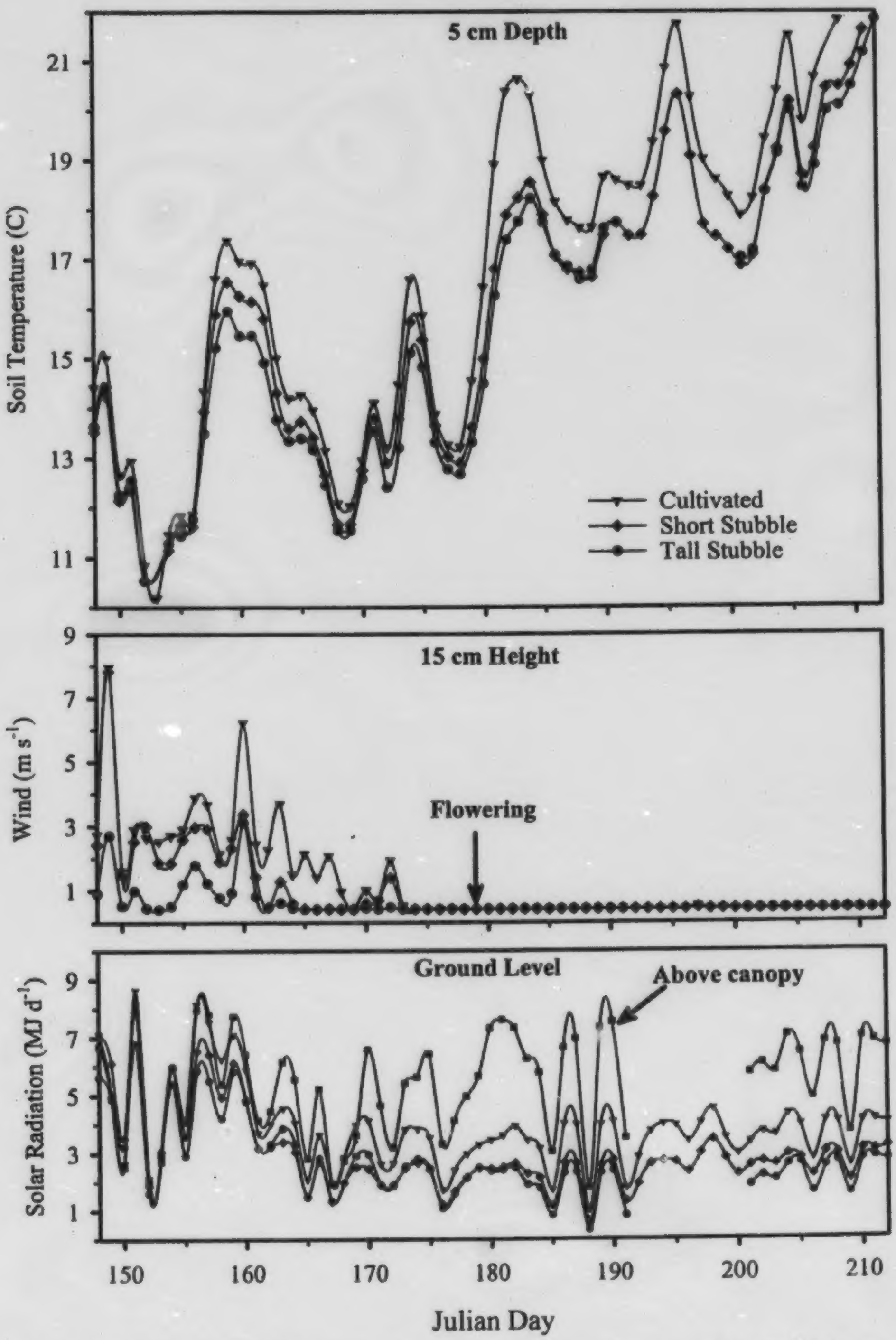

Figure 2.5 Effect of stubble management on the seasonal microclimate of the canola crop at Swift Current in 2000.

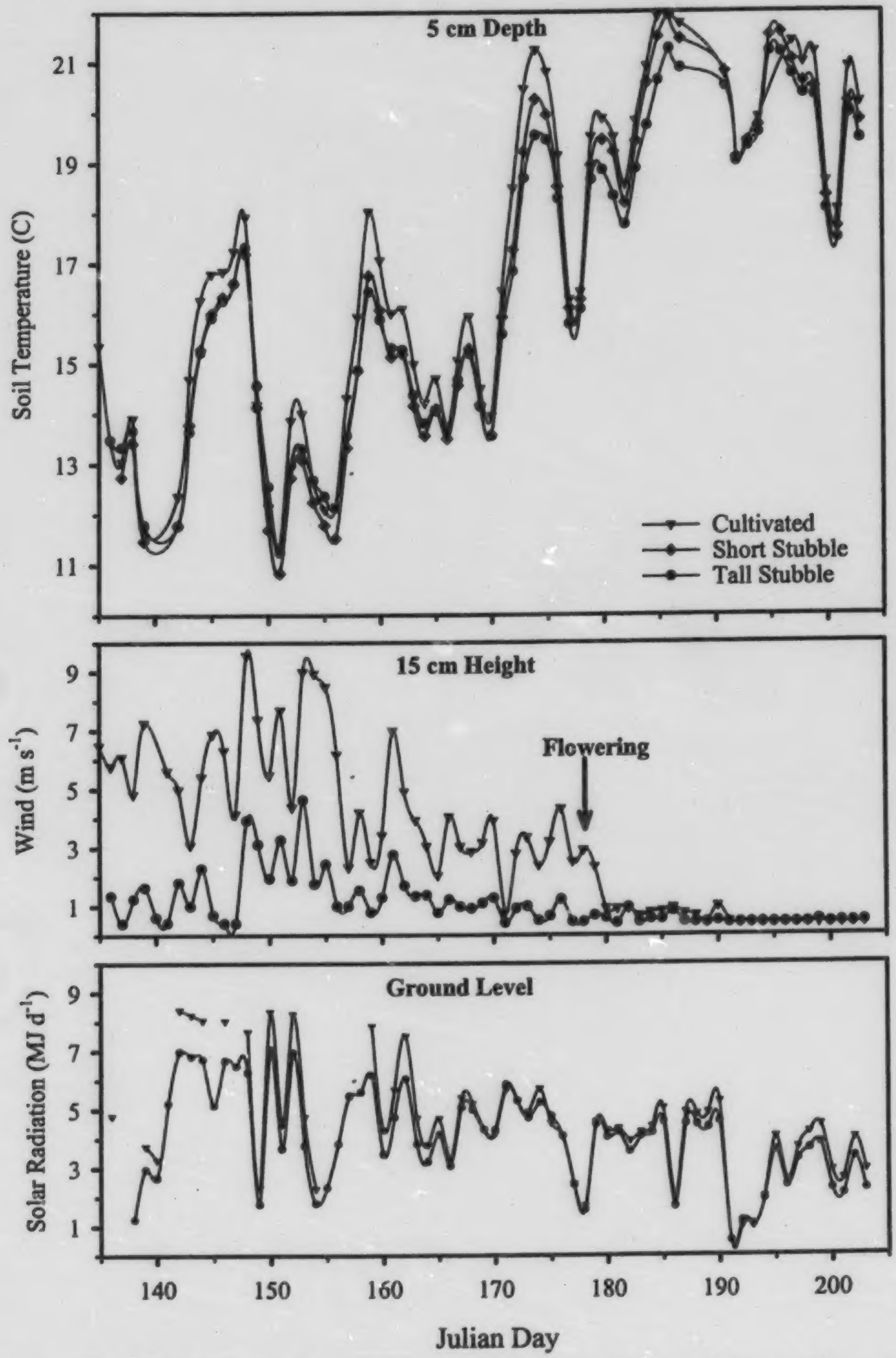

Figure 2.6 Effect of stubble management on the seasonal microclimate of the canola crop at Swift Current in 2001.

CHAPTER 3

Yield Adjustment by Canola Under Different Plant Populations in the Semiarid Prairie

By

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3.1 INTRODUCTION

Canola compensates seed yield over a wide range of populations due to ahigh degree of plasticity (McGregor, 1987). In the short growing season of Canadian prairie, canola has limited time to express potential plasticity compared to other regions of the world where the canola growing season is longer (Mendham and Salisbury, 1995). Therefore, optimum plant population, which is higher than other regions of the world, is more critical in Canada. However, plasticity of a plant depends on the availability of resources such as light, water and nutrients (Sultana 2000) i.e., the greater the availability of resources, the greater will be the expression of plasticity. Thus, under the good moisture supply in southern Manitoba, seeding rates as low as 1.5 to 3.0 kg ha^{-1} were enough to produce maximum grain yield (Morrison et al. 1990a), while under the moderate water supply conditions in Saskatoon, Saskatchewan, higher plant populations (100-200 plants m^{-2} or 4-7 kg ha^{-1}) were needed to produce maximum grain yield (McGregor, 1987). However, when the population increases beyond what the resources can support, seed yield is reduced due to interplant competition (Leach et al. 1999). Thus, excessive vegetative growth due to higher plant population in the semiarid prairie might exhaust limited soil moisture before beginning of the yield formation, leading to 'haying off' of canola. Therefore, information on the plasticity of canola at various plant populations in the temperature and heat stress prone Canadian semiarid prairie is needed.

Canola production in the Canadian semiarid prairie, which was considered marginal for canola production, has been gradually increasing. Reduced plant populations of small seeded crops frequently occur in this region because of poor seeding conditions. Factors reported to reduce plant populations in canola include soil moisture, soil crusting, low temperature, seeding equipment, late spring frost and hail damage (McGregor 1987, Mendham and Salisbury, 1995). In addition, practices such as seeding into standing stubble, fall or early spring seeding, which have been adopted by producers in recent times, increase the challenge for good stand establishment.

In earlier studies on plant population, weed competition was a major factor limiting resource use efficiency at lower plant populations (McGregor, 1987). Therefore, to increase competition, higher plant populations were adopted. Similarly, for the same reason seeding was recommended after killing spring weeds. However, compared to the traditional spring seeding dates, the benefits of early spring or late fall seeding are often substantial and with the availability of herbicide tolerant canola, weeds are easily removed from canola fields (Kirkland and Johnson, 2000). Therefore, a rethinking about optimum plant population is needed.

Past literature has shown the importance of a uniform plant stand for increasing seed yield. However, often non-uniform plant spacing is a rule of nature. Agronomic practices such as fall seeding or seeding into tall stubble are expected to increase non-uniformity in the population stand. Non-uniform plant spacing reduced seed yield in sunflower (Wade 1990) and corn (Pommel and Bonhomme, 1998). Information on the effect of non-uniform plant population on spring canola is lacking. Increased variability in the population was found to reduce seed yield in winter canola ((Hühn 1999; Diepenbrock et al. 2000). Reseeding, however, exposes the temperature sensitive canola crop to increasing seasonal temperatures, which is often reported to reduce seed yield of canola (Nuttal et al. 1992; Angadi et al. 2000). Therefore, we need to determine threshold population levels for making reseeding decision in the semiarid prairie.

Seed yield of canola is a function of population density, number of pods per plant, number of seeds per pod and the individual seed weight. However, the yield structure is very plastic and adjusts over a wide range of populations. The number of pods per plant is the most responsive parameter for seed yield formation (Diepenbrock, 2000) and is determined by the survival of branches, buds, flowers and young pods rather than by the potential number of flowers and pods (McGregor, 1981). Therefore, proper understanding of canola yield formation under semiarid conditions is needed.

The objectives of this investigations were to determine (1) how canola maintains seed yield over a range of population densities, (2) how plant population affects yield component distribution on the plant, and (3) identify the threshold population when re-seeding should be considered.

3.2 MATERIALS AND METHODS

A field study was conducted.over three years (1999 to 2001) at the Semiarid Prairie Agricultural Research Centre, Swift Current, SK, Canada (50°17′ N 107°48′W) located in the Brown and Dark Brown soil climatic zones (Henry and Harder 1991), a semiarid region generally considered marginal for canola production. The soil type was Swinton silt loam. Glyphosate tolerant Argentine canola cv. 'Arrow' was seeded under rainfed conditions on 6 May 1999, 25 April 2000 and 24 April 2001 (Early Spring; ES) using an air drill with 23 cm row widths. The field used for 2001ES trial was extremely dry in early spring. Therefore, the plots were irrigated (about 15 mm) using a portable sprinkler system. Plot area was large enough to display the uniform population treatments only. Therefore to include the non-uniform plant population treatments, an additional trial was seeded under irrigated conditions on 8 June 2001 (Late Spring; LS) using a disc drill with 20 cm row width. The 2001LS trial was irrigated 4 times, first on 29 May (41 mm), second 8 June (14 mm), 11 June (24 mm) and 29 June (29 mm).

All trials were conducted on fallowed fields and the crop previous to fallow was wheat. Vitavax RS (carbathiin + thiram + lindane) seed treatment was used to control seedling fungal diseases and provide protection against flea beetles. Flea beetle (*Phyllotreta cruciferae*), blister beetle (*Lytta nuttalli* and *L. cyanipennis*) and diamondback moth (*Plutella xylostella*) infestations, which were observed at some locations, were controlled with deltamethrin or carbofuran. A higher seeding rate of 12 kg ha^{-1} was used to get a good, uniform population density. In spring, a fertilizer mixture of 84-24-0-22 kg N, P_2O_5, K and S ha^{-1} was uniformly broadcast over the experimental area. Post-emergent Glyphosate application was used to control weeds.

At the 2 to 4 true leaf stage, seedlings were hand thinned to uniform plant stands of 80, 40, 20, 10, and 5 plants m^{-2} and non-uniform plant stands of 40, 20 and 10 plants m^{-2}. Thinning ensured maximum distance between plants in adjacent rows and uniform distribution of population in uniform plant stand treatments. To obtain non-uniform plant stands, seedlings from alternate 1m length from two adjoining rows were removed and when two adjacent rows had the seedlings removed, the next two rows had seedlings retained and vice versa. Thus, by removing half of the plant population from 80, 40 and 20 plants m^{-2}

plots, we obtained 40, 20, and 10 plants m^{-2} non-uniform population plots. Plot sizes ranged from 11.06 m^2 (2001ES) to 26.00 m^2 (2001LS).

At harvest, hand samples were collected from 0.66 to 1.62 m^2 area. Samples were first air-dried and then oven dried. The dry weights and seed weights were used for estimating biomass production per unit area and harvest index. Six rows from the centre of the plot were harvested using a plot combine. Before harvest, 25 mature pods were randomly collected (except in 2000, where terminal pods from 3 randomly selected plants were used) from the canopy and oven dried. They were used for assessing seeds per pod and thousand kernel weights. Pods per plant were counted on three randomly selected plants (5 in 1999).

For detailed analysis of yield adjustment, three plants from the uniform population plots in 2000 and 2001ES were harvested just before swathing. The number of pods produced on the terminal (main) raceme, on individual primary branches and on all other higher order branches at each node were counted. Fertile pods were defined as pods which contained at least one seed. The nodes were counted based on when they initiated flowering branches i.e. top downwards in canola (McGregor, 1981). Pods from main raceme and each primary branch were counted and oven dried separately, while the pods from secondary and higher order branches were pooled for drying. The dry weight of pods, seed weight, and seed number from each main raceme and primary branches were used to calculate seeds per pod, thousand kernel weight and seed to pod ratio on each of those branches separately.

The experimental design for all trials was a randomized complete block design with 3 (2000 and 2001LS) and 4 (1999 and 2001ES) replicates. Year and locations were combined and termed as 'environment'. Wherever more than one sample was taken from each plot, the mean of the observations was used for analysis. Weather conditions varied significantly during the experimentation. Therefore, to understand canola response under favorable and unfavorable growing conditions, all grain yield and yield forming traits from each environment were analyzed separately. To generalize the results, data on main grain yield and yield forming traits were averaged over four environments and significant effect of population was determined using the analysis of variance technique (GLM procedure, SAS Inc, 1985). To understand the plant population effect under different seed yield potential, grain yield from each environment from each population were normalized to the grain yield at 80 plants m^{-2} and regressed against plant population.

3.3 RESULTS AND DISCUSSION

3.3.1 Weather Conditions

Weather parameters were collected from the Environment Canada Weather Station located 50 to 300 m from the experimental locations (Fig. 1). In general, the growing conditions were extremely favourable for a good canola crop in 2000, while they were extremely stressful in 2001. Seasonal temperatures varied substantially during the study. For example, maximum temperatures in May, June and July of 1999 were 2.4 to 3.3 °C cooler than normal, while maximum temperatures in 2001 were 2.0 °C and 3.8 °C warmer than the normals for May and August. However, in both 1999 and 2000 snow fall occurred a few days after seeding and minimum temperature was below zero. Since the crop was either small or yet to emerge, no adverse effect was observed. As well, the variation in monthly mean minimum temperature was smaller than the variation in the monthly mean maximum temperature. Precipitation was fairly well distributed in 1999 and 2000, except for August, which received only 30 to 40 % of long term average. In contrast, 2001 was extremely dry during winter months, which severely reduced soil water recharge in spring, followed by an extremely dry growing season with only 40 to 50 % of the normal rainfall amounts during May and June. Later growth stages, especially in the late spring seeded trial, were also severely affected by drought when only 7% of the normal rainfall fell during August. The analysis of 1885 to 2001 climatic records for Swift Current revealed that 2001 was second driest and fifth warmest year on record (Judiesch and Cutforth 2002). Thus, the 2001 experiement was severely stressed due to higher temperatures and very low rainfall.

3.3.2 Biomass Production

The effect of plant population on biomass production varied with environment (Table 1). In general, canola maintained biomass production over a wide range of populations. In 2000, there was no effect of population, while the largest effect of population on biomass production was in 2001LS. The LAI of lower population is often reported to be lower than that for higher plant populations. The LAI of 5 plants m^{-2} measured in 2001ES was 14 to 46% of 80 plants m^{-2} between 55 to 79 days after seeding (data not presented). Thus, the lack of good ground cover at lower populations (Fig 2 and 3) prevented canola from efficiently utilizing the solar radiation and produced lower biomass. However, mean biomass produced at lower plant populations in the three environments was not statistically different from the higher plant population (Fig. 4). Similarly, non-uniform plant stand had no effect on mean biomass. Thus, the plasticity of the canola plant maintained biomass production over a wide range of uniform as well as non-uniform population densities, although the tendency was for biomass to decrease as plant population decreased.

3.3.3 Seed Yield

Canola maintained seed yield over a wide range of population (Table 1). The significant yield reduction occurred only when the population was reduced by more than half. Reducing population from 80 plants m^{-2} to 20 plants m^{-2} reduced seed yield by 1% in 2000 to 36% in 2001LS. Regression of normalized seed yield response with population densities indicated a strong quadratic relationship ($r^2>0.80$) (Fig 5). The regression also indicated that in environments with higher yield potentials (eg. 2000), yield compensation by remaining plants occurred over a wider range of populations, while the yield compensation in environment with lower yield potentials (eg. 2001LS) ceased at much higher populations. These results suggest that canola seed yield plasticity is dependent upon resource availability. Similar to these observations, McGregor (1987) observed less than 20% seed yield reduction with population reductions from 100-200 plants m^{-2} to 40 plants m^{-2} under non-stressful environments, but more than 40% under stressful environments. At very low population (<8 plants m^{-2}) seed yield dropped rapidly, indicating a lack of interplant competition to limit plant growth at those densities (McGregor 1987). When we compared the yield reduction as population reduced from 10 to 5 plants m^{-2}, the yield drop was more than 50% in only the 2000LS trial. These results suggest that for our experiments interplant competition existed even below 10 plants m^{-2}, unless it was extremely stressful (such as occurred in 2001LS). The seeding dates in the present study were 17 to 34 days earlier compared to the study of McGregor (1987), providing favorable growing conditions (Kirkland and Johnson, 2000). In addition, use of a Glyphosate tolerant cultivar helped limit weed competition. Thus, the canola in the present trials probably utilized the more favorable conditions and exhibited greater plasticity compared to the McGregor's study.

Mean seed yield of the four environments reduced curvilinearly with reductions in plant population (Fig. 5). Because of plasticity, 80 and 40 plants m^{-2} produced similar yields, and reducing population to 20 plants m^{-2} reduced seed yield by only 18% (Fig. 4). However, further decreases in population to 10 and 5 plants m^{-2} reduced seed yield by 38 and 47%, respectively. Thus, a population of 20 plants m^{-2} should be acceptable for a early spring or late fall seeded canola in the semiarid prairie.

Seed yields of non-uniform plant populations were similar to uniform populations in all three environments (Table 1). Limited observation in winter canola indicated that increasing variability in plant stand deceased seed yield (Hühn 1999). Similarly, non-uniformity reduced seed yield in corn by reducing sink capacity (missing cobs) (Pommel and Bonhomme, 1998), and in sunflower by increasing lodging (heavier heads) (Robinson et al. 1982), although yield compensation was noticed in both crops. Canola has a strong ability to compensate for a reduced sink by increasing branching and increasing podding. In addition, opening the canopy at uneven populations not only exposes the lower leaves to radiation but also adjusts the leaf architecture morphologically to intercept a larger proportion of incoming radiation (McWilliam 1995); these findings have also been observed in corn (Pommel and Bonhomme, 1998). Thus, both improved sink and source might have contributed to yield compensation in non-uniform plant stands in the present study.

Harvest index was stable over most environments except for the extremely stressful conditions of 2001LS (Table 2). There was no effect of uniform and non-uniform population on harvest index (Fig 6). Thus, seasonal environments were more significant in affecting harvest index than populations. For example, under low yield potential conditions of 2001LS harvest index deceased with decrease in population. This suggests that the extra energy invested in vegetative structures such as primary and secondary branches did not increase seed yields under stress situations.

3.3.4 Yield Components

The number of pods produced per plant increased with decreasing plant population (Fig. 6 and 7; Table 2). However, increased pod number only partially compensated for decreased population. Pod number compensation also depends on growing conditions (Diepenbrock 2000). For example, reducing plant population from 80 to 40 Plants m^{-2} in 1999 and 2000 increased the number of pods per plant by 81 and 74 %, while the same population variation in 2001ES and 2001LS increased pod number by 28 and 36%, respectively. Thus, under the more favourable conditions of 2000 very low populations (5 plants m^{-2}) produced 6 times more pods per plant than high populations (80 plants m^{-2}). Across environments there was a strong response to increasing pods per plant with decreasing populations, although increasing pod numbers only partially compensated pod numbers in a unit area. For example, 5 plants m^{-2} produced 4 times more pods per plant than 80 plants m^{-2}, a 16 times higher population. Non-uniform plant stands produced pod numbers similar to those produced by the corresponding uniform plant stand, except at 10 plants ha^{-1}, where pods per plant were reduced by the non-uniform plant stand.

The other yield parameters like seeds per pod and thousand seed weight were not affected by the population variation in any of the environments (Table 3 and Fig. 8).

McGregor (1987) also found that seeds per pod and seed weight were not as strongly influenced by population as were pods per plant. Early formed pods on the top of the canopy or on the main raceme have the developmental advantage (Mendham and Salisbury, 1995), that might have masked the smaller variations in seeds per pod or seed weight in the present study.

3.3.5 Nodal Analysis

Nodal distribution of yield components were compared for 2000 (Fig. 3.9), a year with high yield potential, and for 2001LS (Fig. 3.10), a year with low yield potential. The increase in the number of pods per plant was achieved by both an increase in pods per node (both on primary and secondary branches) and an increase in primary branches (Fig. 3.8). However, the increase in pods per node was more significant than the increase in the number of primary branches. The primary response of canola to lower plant populations was increased branching. That was followed by increased retention of pods at each branch. As the canopy becomes less dense (opens) at lower populations, light penetrates deeper into the canopy which favours retention of leaf area (McWilliam et al. 1995). Thus, improved photosynthetic source stimulates better retention of pods.

Comparing main stem nodes in 2000 and 2001LS (top to bottom), showed a strong effect of population density on the distribution of pods on primary and secondary branches (Fig. 3.9 and 3.10). The number of pods produced by the upper few nodes (also terminal receme; data not presented) did not differ with population variations. At 80 plants m^{-2}, canola produced pods on the terminal branch and primary branches on the upper few nodes, and the number of pods decreased almost linearly with increase in node number. At 5 plants m^{-2}, peak pod production was observed a few nodes lower in the canopy before significant decrease in pod production was observed. Canola rarely uses secondary or higher order branching to increase pod number, which was evident from comparing 2000 and 2001LS data. First, only very low population densities adopted secondary branching to compensate productivity. Second, the extent of using secondary branching was much lower under stressful conditions of 2001LS compared to 2000. Similar to pods produced on primary branches at lower populations, peak secondary pod production was lower in the canopy. Observations in cotton suggested that too many monopodial branching is not an efficient strategy for increased productivity, which may apply to canola also. At higher plant populations a greater fraction of pods were formed on the upper canopy and as plant population were reduced, more pods were formed lower on the plant. In canola, flowering takes place in acropetal succession; while branching takes place in basipetal succession (Mendham and Salisbury 1995). Racemes on the upper portion of the canopy are formed early and mature early, which provides a maturity advantage for high density canola (McGregor 1981). Similar results were made in the present study (data not shown).

Seeds per pod and thousand seed weight in the upper portion of the canopy were similar among different population treatments. This again supports that the number of pods is more responsive to population than other yield parameters. Reductions in seeds per pod and seed weight started at higher nodes in denser canopies compared to sparser canopies. This again may be a result of lack of source (photosynthesis from lower leaves and lower pods) to support pod filling at higher plant densities (McWilliam 1995). However, comparing seed to pod ratio suggests that pods on lower nodes were less efficient compared to those on upper nodes. This suggests that later formed lower pods had less time to retranslocate photosynthates to seeds. This may have some implications for quality of grain at lower plant populations.

3.4 SUMMARY

Canola exhibited high levels of plasticity to maintain seed yield over a wide range of populations grown under semiarid conditions. Reducing population by 50% from 80 to 40 plants m^{-2} and non-uniform plant stand had no effect on seed yield. The plant structure adapted to the growing conditions, thus increasing branches and pods per plant as populations reduced. However, expression of plant plasticity did not fully compensate grain yield reductions as plant populations decreased. Number of pods per plant was the most important factor responsible for yield compensation, while seeds per pod and seed weight did not significantly contribute to yield compensation. Detailed observations of yield formation characteristics indicated that plant density only affected seeds per pod and seed weight for the lower nodes. Increase in pods per plant was achieved through both increased branching and increased pod retention at each node.

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Table 3.1 Biomass and seed production of Argentine canola cv. Arrow in response to variations in population densities at Swift Current during 1999 to 2001.

	Year			
Population	1999	2000	2001 ES*	2001 LS
(plants m^{-2})		Biomass (kg ha^{-1})		
80	7073a	8342a	-	3718a
40	5903a	7678a	-	3011ab
20	5085ab	8955a	-	2896ab
10	5306ab	7557a	-	1845c
5	2997b	10594a	-	1795c
40 NU‡	5883a	9775a	-	2756abc
20 NU	6378a	7643a	-	2598bc
10 NU	5827a	8000a	-	2903ab
		Seed Yield (kg ha^{-1})		
80	1978a	2733a	1352a	418a
40	1677ab	2765a	1092ab	325ab
20	1567b	2703a	881bc	268bc
10	1152d	2213b	679c	88de
5	802e	2192b	573c	35e
40 NU‡	1462bcd	2890a	.	262bc
20 NU	1527bc	2494ab	.	184bcd
10 NU	1217cd	2521ab	.	138cde

* ES and LS stand for early spring seeding and late spring seeding, respectively.

‡ Nonuniform Population. For example, 40NU is similar to 80 plants m^{-2} but after every 1 m length of two adjacent rows 1 m length of plants is missing.

Table 3.2 Harvest index and pods per plant for Argentine canola cv. Arrow in response to variations in population densities at Swift Current during 1999 to 2001.

	Year			
Population	1999	2000	2001 ES*	2001 LS
(plants m^{-2})	Harvest Index			
80	0.28a	0.36a	-	0.11a
40	0.29a	0.36a	-	0.11a
20	0.36a	0.31a	-	0.09ab
10	0.22a	0.30a	-	0.05cd
5	0.27a	0.21a	-	0.02d
40 NU‡	0.25a	0.30a	-	0.10ab
20 NU	0.25a	0.34a	-	0.07bc
10 NU	0.28a	0.33a	-	0.05cd
	Pods $plant^{-1}$			
80	93d	97c	100c	44d
40	168c	169bc	128c	60d
20	216b	237bc	197bc	112bc
10	276a	472a	281ab	124b
5	279a	582a	358a	216a
40 NU‡	121d	259b	-	68cd
20 NU	163c	218bc	-	124b
10 NU	172c	-	-	147b

* ES and LS stand for early spring seeding and late spring seeding, respectively.

‡ Nonuniform Population. For example, 40NU is similar to 80 plants m^{-2} but after every 1 m length of two adjacent rows 1 m length of plants is missing.

Table 3.3 Seeds per pod and thousand seed weight of Argentine canola cv. Arrow in response to variations in population densities at Swift Current during 1999 to 2001.

	Year			
Population	1999	2000	2001 ES*	2001 LS
(plants m^{-2})		Seeds Pod^{-1}		
80	22.3	22.4	-	23.1
40	23.0	23.7	-	20.1
20	23.2	24.7	-	23.6
10	24.1	25.8	-	23.5
5	25.4	21.8	-	20.1
40 NU‡	24.8	16.0	-	19.8
20 NU	23.9	25.1	-	21.3
10 NU	22.9	-	-	19.8
		Thousand Seed Weight (g)		
80	2.70	3.37	-	3.04
40	2.95	2.88	-	2.77
20	3.06	3.03	-	2.75
10	2.89	3.06	-	3.00
5	3.08	2.91	-	2.71
40 NU‡	3.07	3.58	-	2.96
20 NU	3.13	3.41	-	3.08
10 NU	3.05	-	-	2.87

* ES and LS stand for early spring seeding and late spring seeding, respectively.

‡ Nonuniform Population. For example, 40NU is similar to 80 plants m^{-2} but after every 1 m length of two adjacent rows 1 m length of plants is missing.

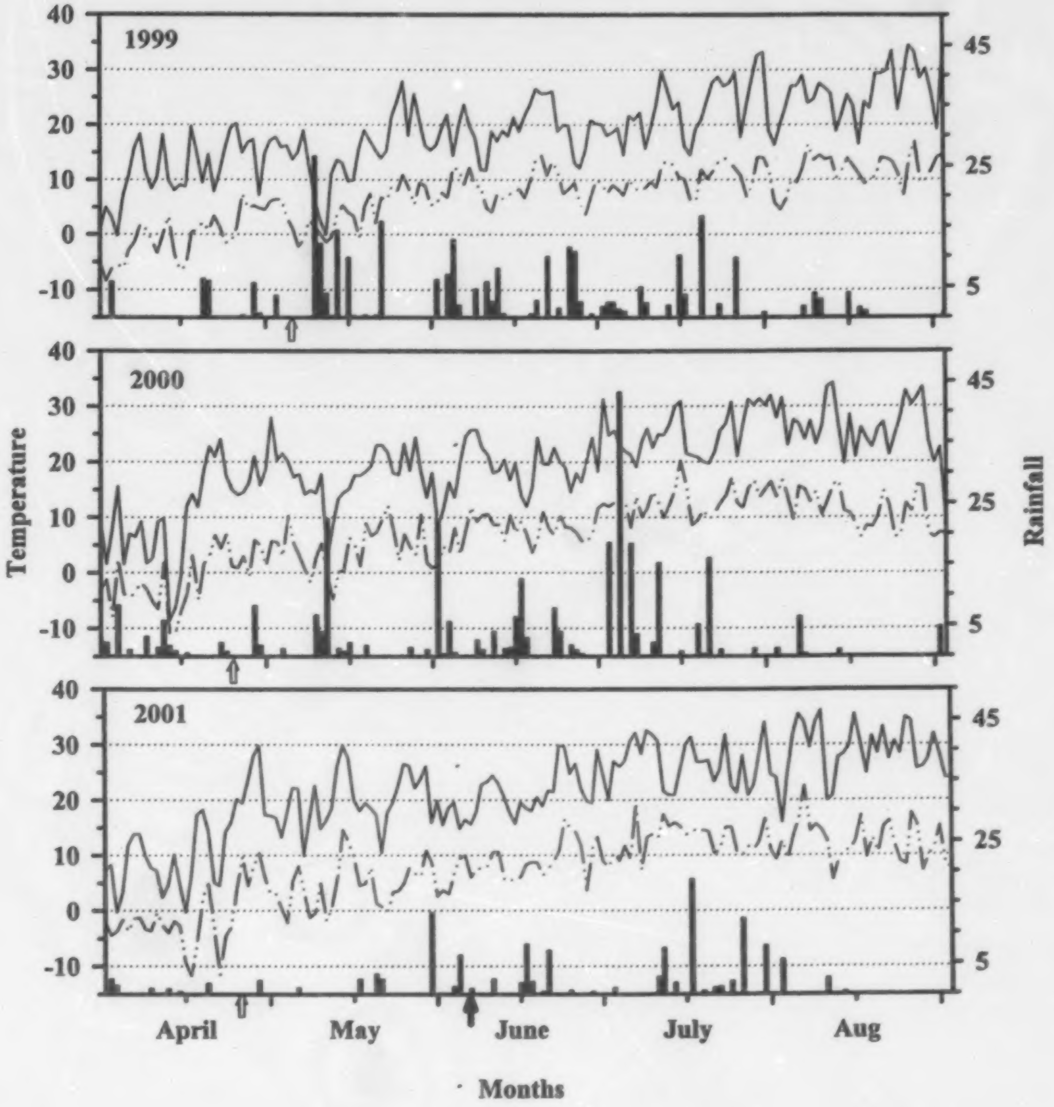

Fig. 3.1 Maximum (solid line) and minimum (dashed line) temperatures and rainfall (vertical bars) at Swift Current during 1999 to 2001.

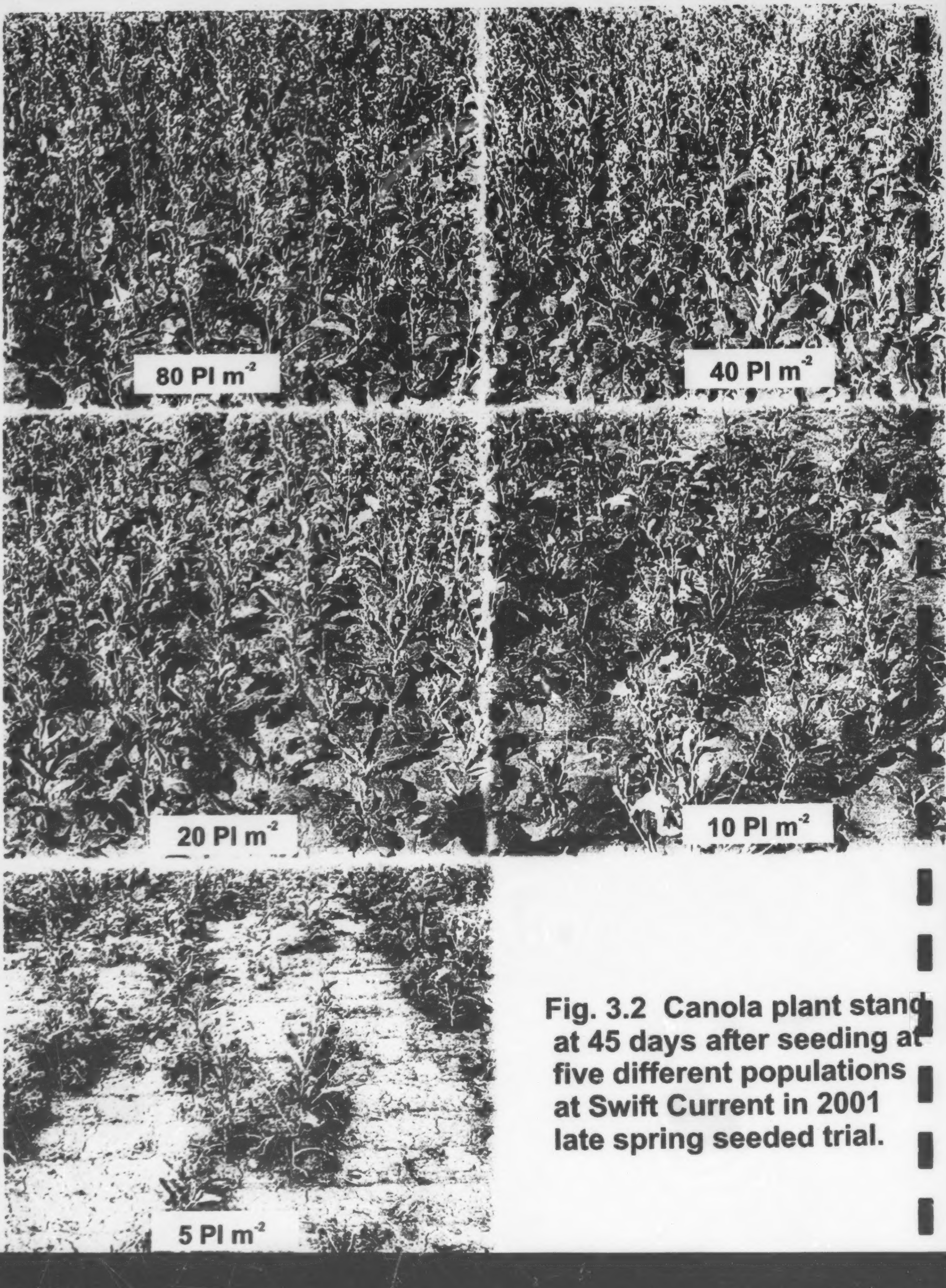
80 Pl m^{-2}
40 Pl m^{-2}
20 Pl m^{-2}
10 Pl m^{-2}
5 Pl m^{-2}

Fig. 3.2 Canola plant stand at 45 days after seeding at five different populations at Swift Current in 2001 late spring seeded trial.

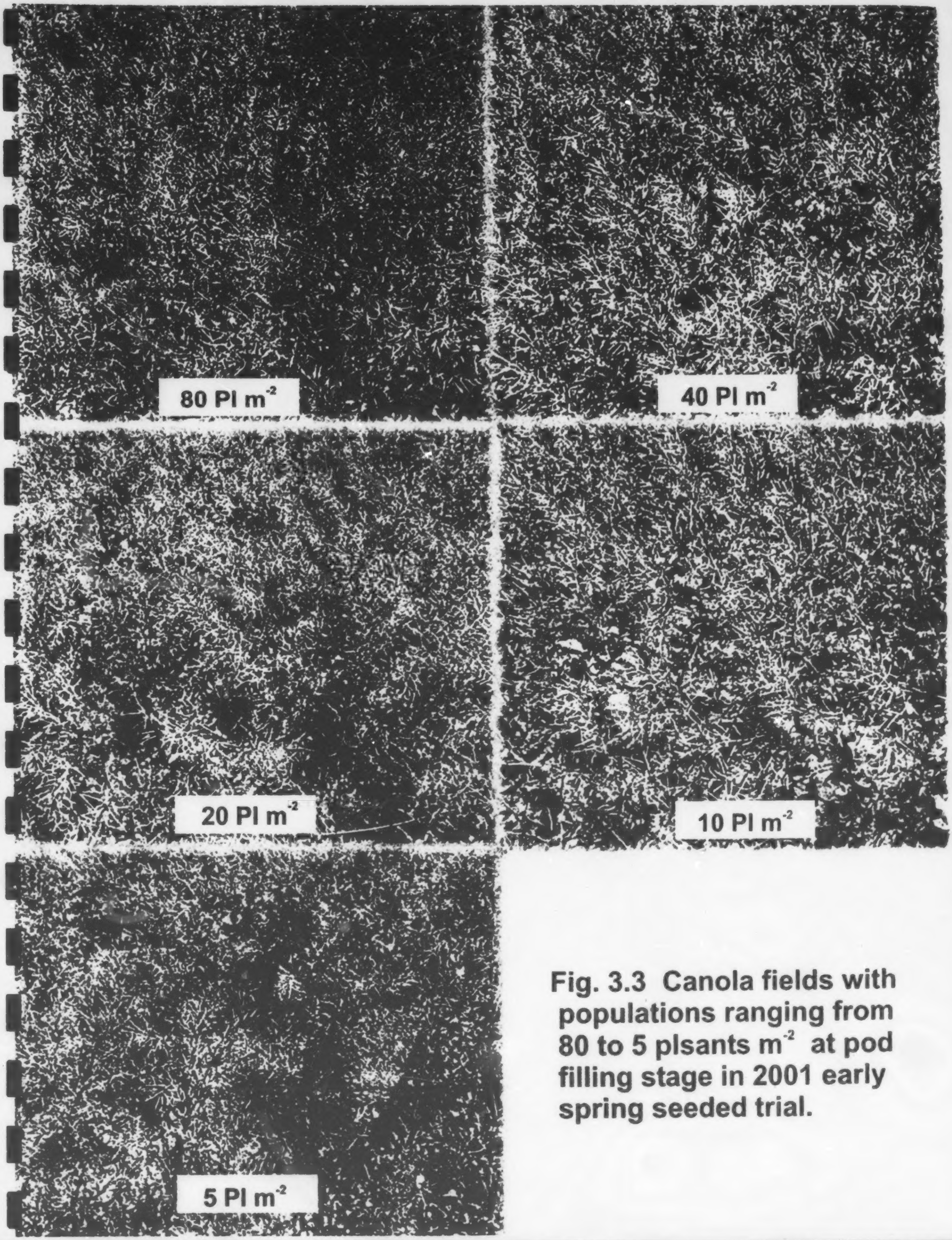
80 Pl m^{-2}
40 Pl m^{-2}
20 Pl m^{-2}
10 Pl m^{-2}
5 Pl m^{-2}

Fig. 3.3 Canola fields with populations ranging from 80 to 5 plsants m^{-2} at pod filling stage in 2001 early spring seeded trial.

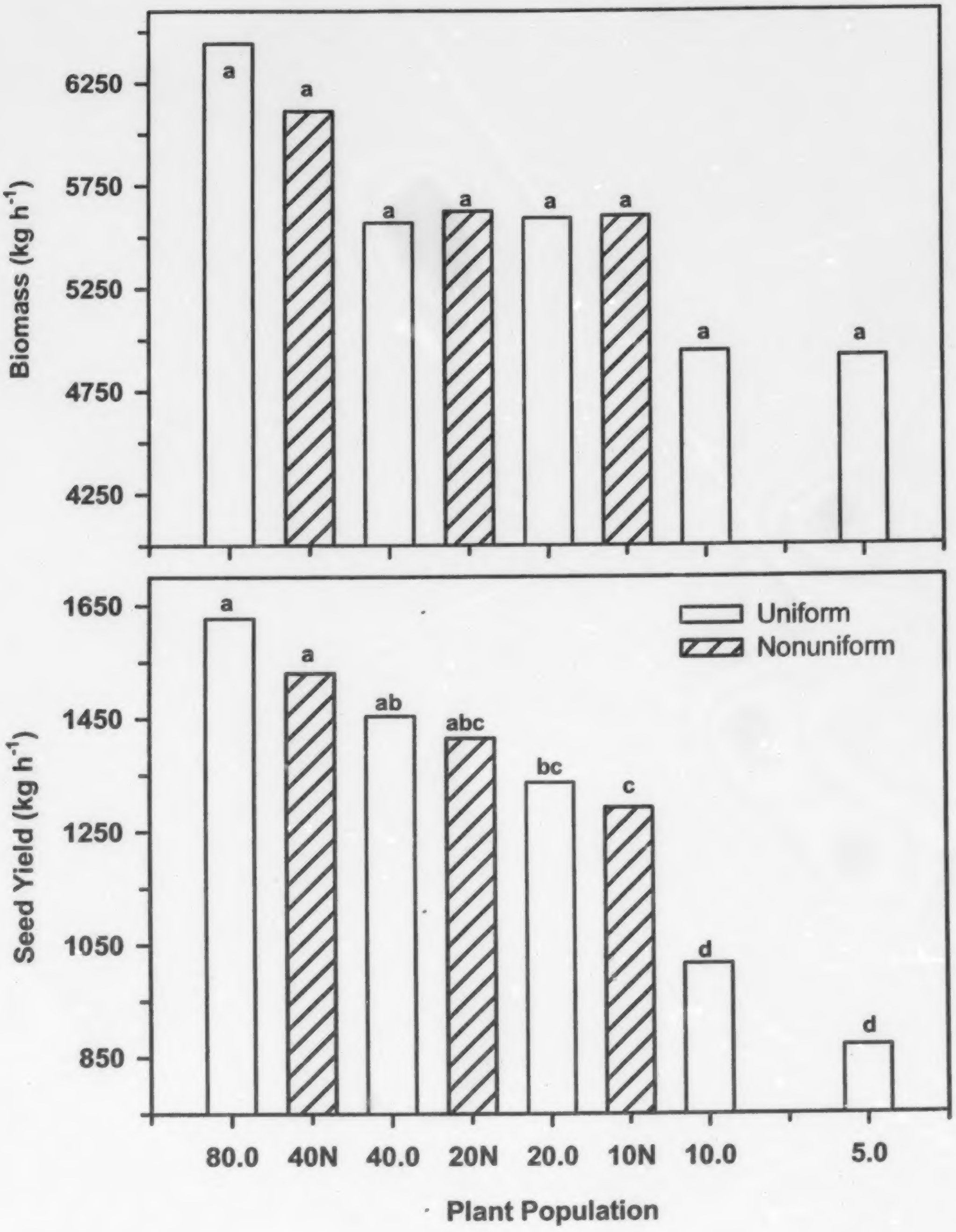

Fig. 3.4 Mean biomass production and seed yield in canola in response to different uniform and non-uniform populations over four environements at Swift Current.

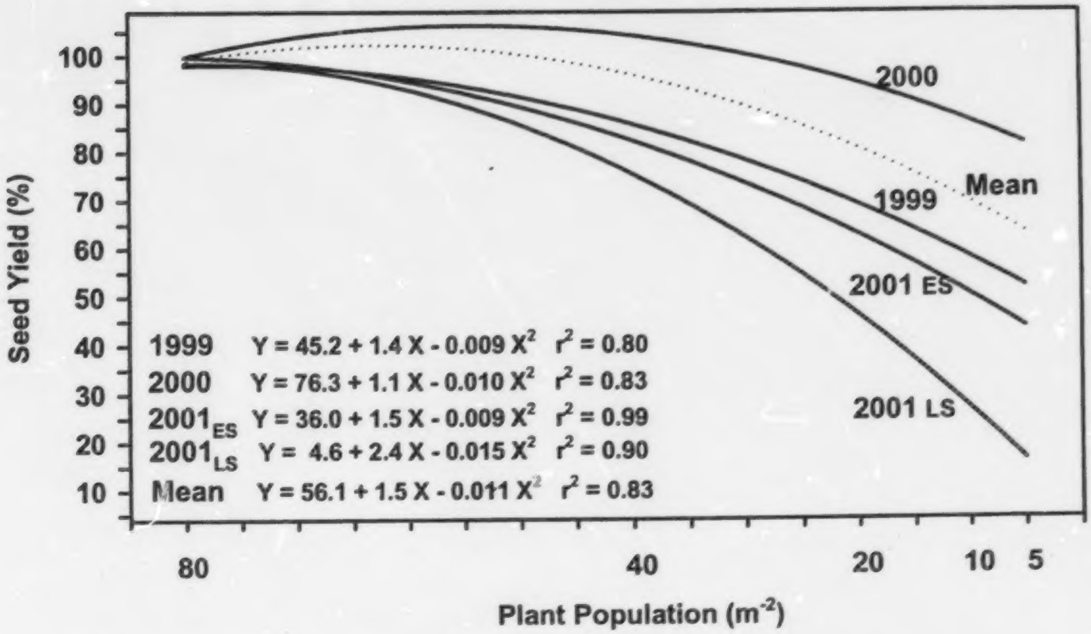

Fig. 3.5 Relationship between normalised seed yields and plant populations in four different environemnets in Swift Current. Dotted lines is the mean of four environments.

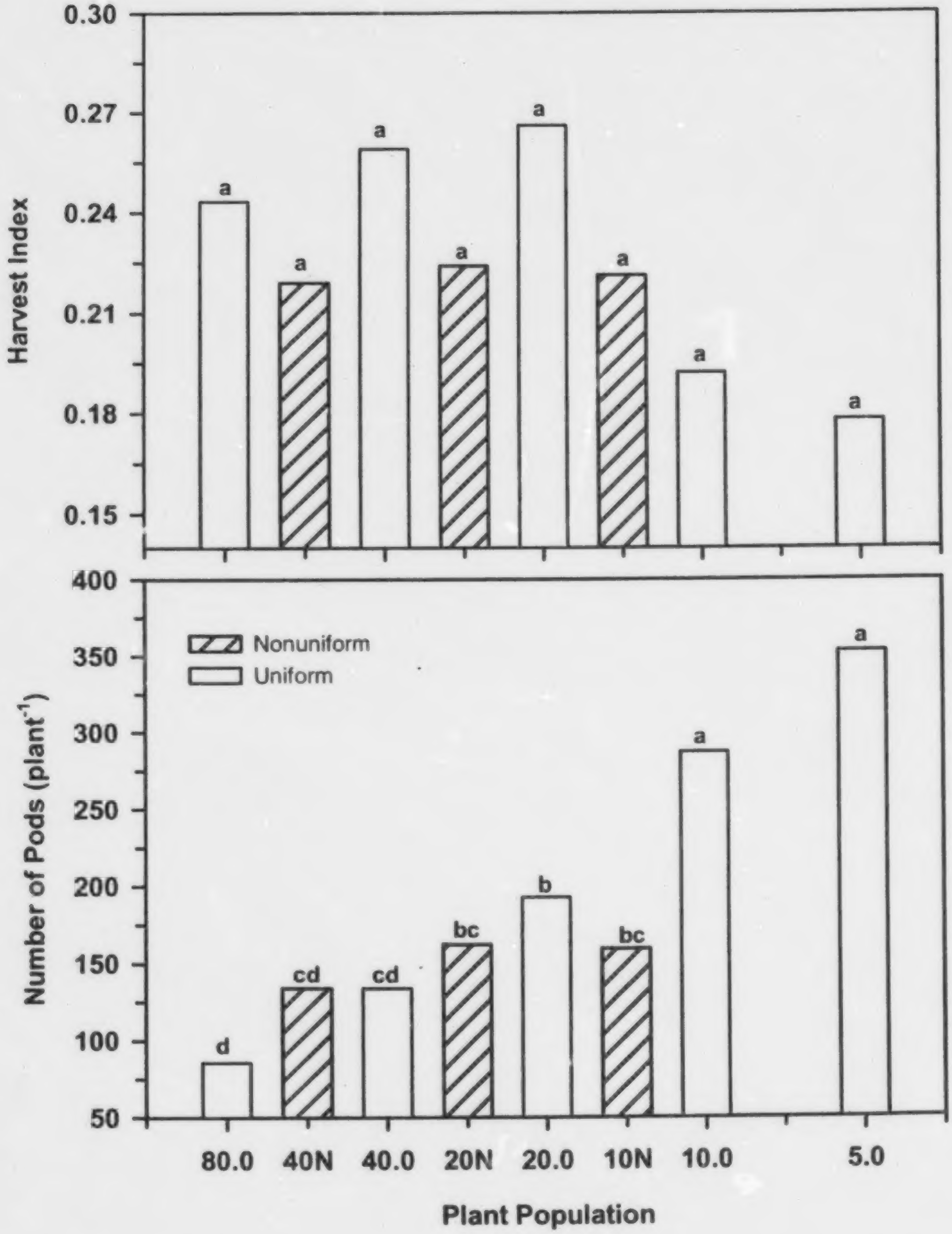

Fig. 3.6 Harvest index and number of seeds per plant in canola in response to uniform and non-uniform populations over four environements at Swift Current.

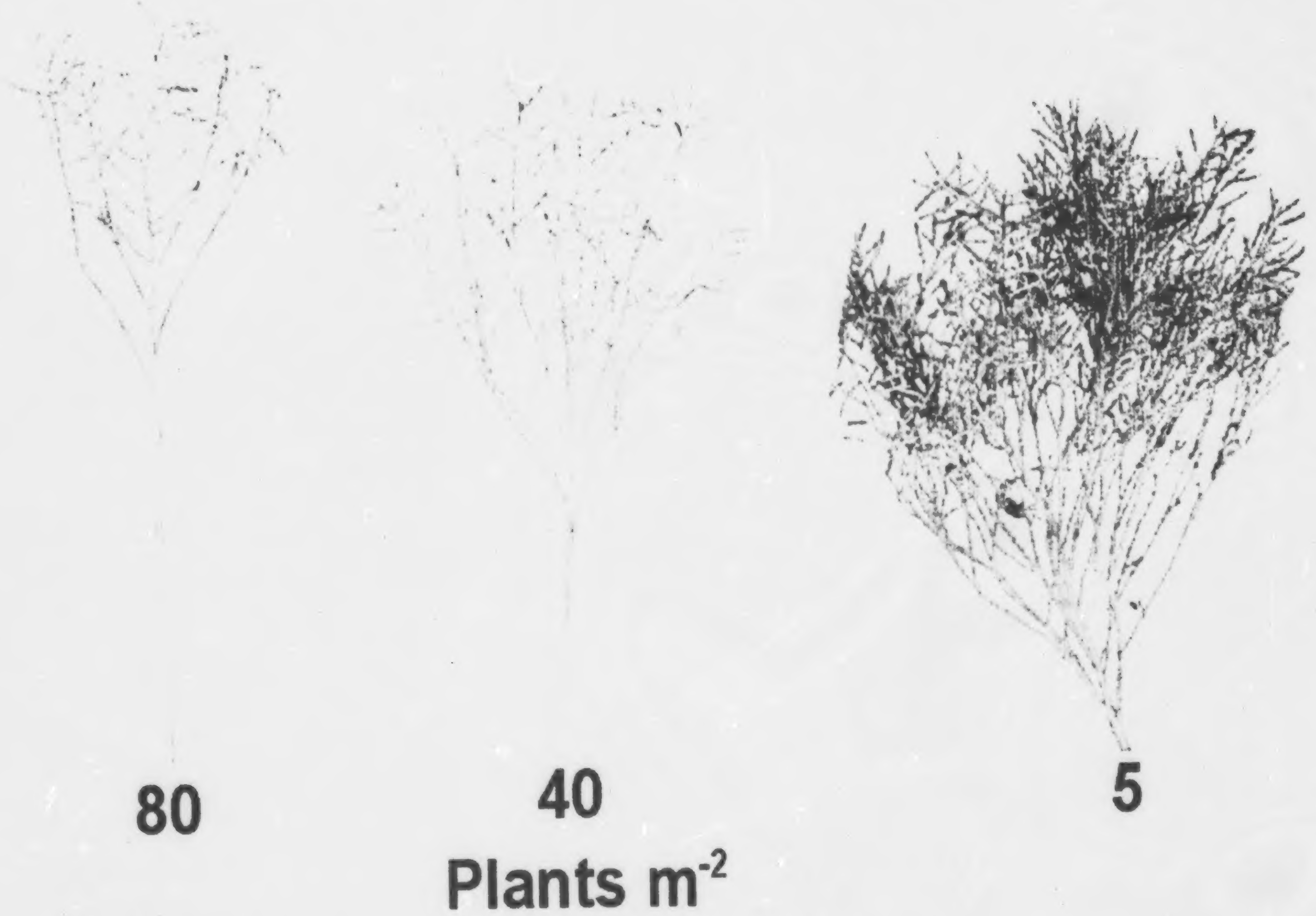
80
40
5
Plants m-2

Fig. 3.7 Effect of plant population (uniform) on branch and pod formation in canola in 2000.

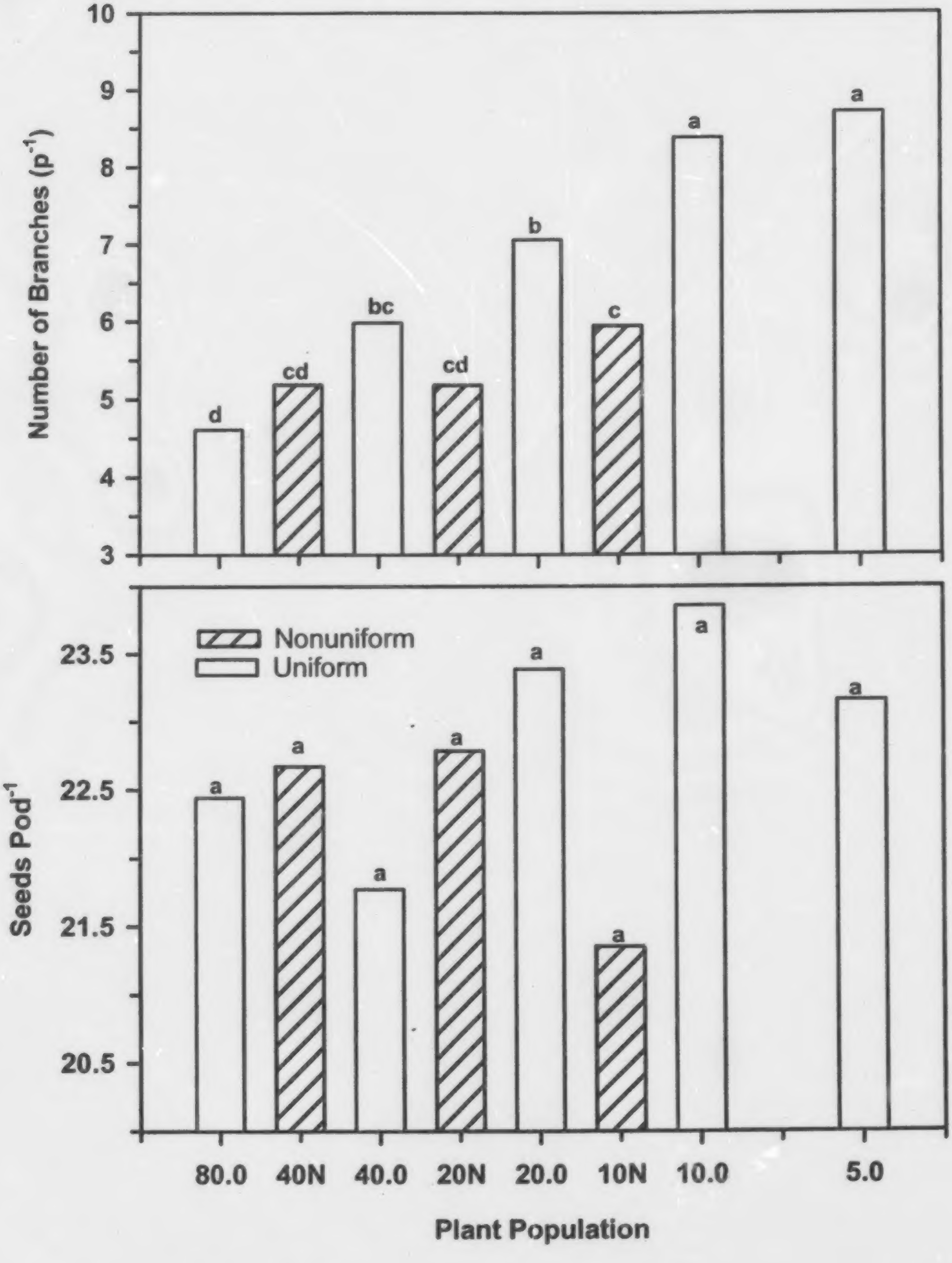

Fig. 3.8 Mean number of primary branches per plant and mean number of seeds per pod in canola in response to uniform and non-uniform populations over four environements at Swift Current.

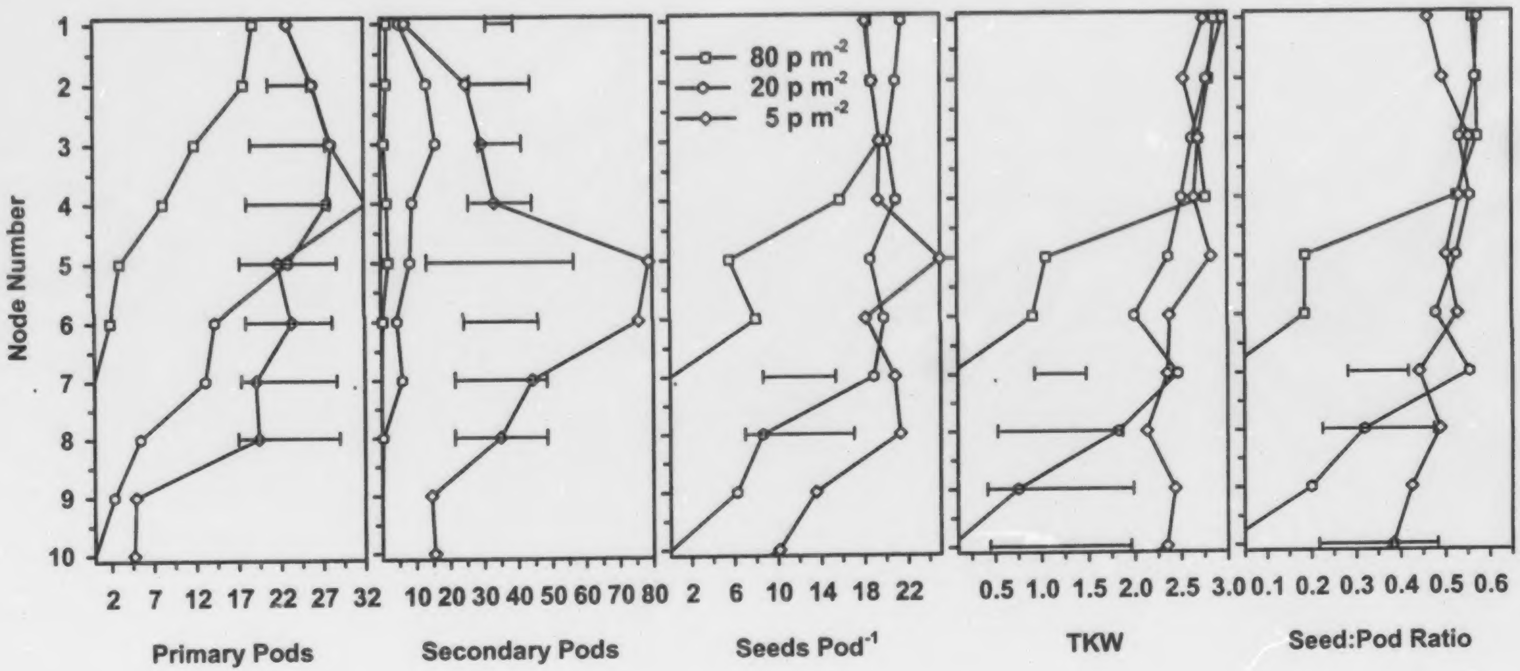

Fig. 3.9 Distribution of yield components on different nodes for canola cv. Arrow at different population densities in 2000 at Swift Current. The horizontal bars are LSD values at 0.05 p. For clarity, only three populations are plotted.

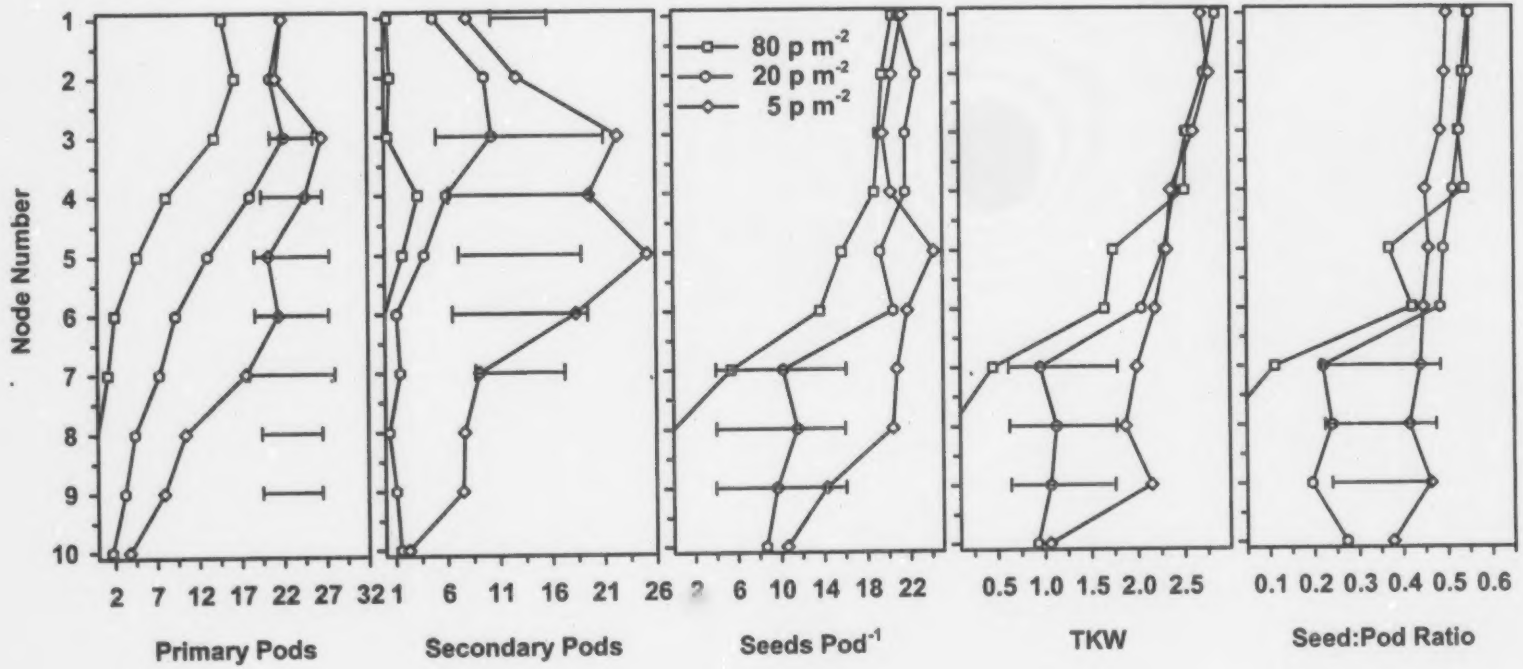

Fig. 3.10 Distribution of yield components on different nodes for canola cv. Arrow at different population densities in 2001ES at Swift Current. The horizontal bars are LSD values at 0.05 p. For clarity, only three populations are plotted.

CHAPTER 4

Determination of the Water Use and Water Use Response of Canola to Solar Radiation and Temperature by Using Heat Balance Stem Flow Gauges

By

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ABSTRACT

Sap flow gauges using heat balance have been reliable for measuring realtime transpiration in a number crops. However, information on the accuracy of sap flow gauges in canola is lacking. Therefore, a study was conducted to validate sap flow system in canola and to observe sap flow response to variations in temperature and solar radiation. There were strong relationships between sap flow measured with sap flow gauges and actual transpiration over short periods of 1 h (r^2=0.93 and RMSE=2.34 g h^{-1}), and over a longer periods of one day (r^2=0.83 and RMSE= 48 g d^{-1}), although sap flow slightly overestimated transpiration. In both cases the slope was not significantly different from 1. Water use in canola, estimated with sap flow gauges or from actual transpiration measurement, was dependent upon temperature (r^2=0.94 to 0.96): water use increased until day-time temperatures reached 36 °C, after which water use decreased, presumably by stomatal closure. Sap flow followed solar radiation trends in the field. Heat is lost or dissipated from the gauges convectively as the sap flows through the stem, conductively through the solid stem material, and radially into the surrounding air. As the convective proportion of the heat loss from the gauge increased, the accuracy of the water use estimation using the sap flow gauges increased. For sunny days, convective heat loss through sap flow accounted for a major portion of the total heat input to the gauges, while on cloudy days radial heat loss from the gauges accounted for a major portion of the heat input. Thus, at low sap flow rates during cloudy days, the possibility of error in the sap flow system was high. Overall, sap flow in canola was strongly related to daily solar radiation (r^2=0.97). The sensitive response to

weather variations and the possibility of improving the accuracy at high flow rates in the field makes sap flow gauges a viable option for measuring realtime transpiration in canola.

INTRODUCTION

Soil water balance method or micro-meteorological methods have been used to estimate evapotranspiration for a long time. However, those processes cannot separate transpiration from evapotranspiration. Recently, technologies to measure real-time canopy transpiration by measuring sap flow through the stem have been developed (Cohen et al. 1993). The success of this technology has furthered our understanding of canopy water relations. However, past studies on the validation of this technology have clearly demonstrated that its success depends on crop species and crop specific information is needed before using it (Cohen et al. 1993).

Estimating sap flow by the heat balance method, where energy entering and leaving the system is measured to quantify the heat transported by the sap stream to calculate sap flow, is one of the important methods used to measure real-time transpiration by plants (Sakuratani 1981). A number of studies have described the heat balance method in detail (Baker and Van Bavel 1987; Ham and Heilman 1990). In summary, a small flexible foil heater of fixed width that encircles the stem completely is used to emit constant energy (Q) to heat a small portion of the stem. Each heat balance gauge is insulated with foam covers, weather shields and multiple layers of aluminum foil to ensure a steady state condition. Therefore, heat input to the system equals outward or radial heat loss (Qr) through the foam sheath that encircles the heater, the axial heat loss (Qv) in both directions and the convective heat dissipated (Qf) by the sap flow. A series of thermopiles located inside and outside of the gauge shield are used to estimate Qr, while thermocouples located at known distance above and below the heater measure stem temperatures to estimate Qv. The remaining unaccounted heat dissipated convectively through sap flow will be converted to a sap flow rate through calculations involving the estimate of Qf, the cross sectional area of the stem and the heat conductivity of sap (assumed to be the same as water).

Ever since Sakuratani (1981) demonstrated the use of heat balance method for measuring transpiration in herbaceous plants, the method has been verified in a number of plant species (Zhang and Kirkham 1995). The heat balance method is non-destructive and requires no calibration. The main advantages of sap flow system include; 1) sensor attachment will not affect the transpiration behavior of the plant, 2) reliability of the data can be studied from raw data, 3) the potential accuracy is high, and 4) long-term observations are possible. The heat balance technique has been used for diverse purposes like studying weed-crop competition, partitioning sap flow into various portions of the plant, response to high CO_2 concentration, genetic variation for water relations, response to different stresses, and herbicide resistance (Akanda et al. 1996). However, the information on use of this technology on canola is lacking.

Canola is the most important oilseed crop in Canada. In recent years, canola production has expanded in the semiarid prairie with increased water stress compared with traditional area of production in the subhumid prairie. Successful validation of the sap flow gauges for canola will allow use of this technology to generate information on realtime transpiration in response to weather conditions like solar radiation, wind, temperature and to management practices like plant population. Such information will be extremely useful in adaptability and modeling studies of canola under different agroclimatic conditions.

The first objective of this research was to determine the accuracy of sap flow gauges using heat balance for measuring transpiration in canola. The second objective was to use sap flow gauges to quantify canola response to weather parameters like light and temperature.

MATERIALS AND METHODS

Sap flow measurements were made during 1999 and 2000 in growth chamber, greenhouse and field experiments. All the experiments were conducted at the Agriculture and Agri-Food Canada Research Centre at Swift Current, SK, Canada (50°17′ N 107°48′W). A *Brassica napus* (L.) cv. ‘Quantum’ was used for indoor studies while, cv. ‘Arrow’ was used for the field study. Seeds were treated with Vitavax RS (carbathiin + thiram + lindane) before seeding. In indoor studies, 5 to 6 seeds were planted per pot and at the 2 leaf stage, thinned to one healthy plant. To ensure adequate number of healthy plants for experimentation, extra pots were maintained in all indoor trials. In the field trial, plots were thinned at 4 leaf stage to a plant population of 80 pl m^{-2}. In all trials, water and fertilizer were not a limitation for plant growth.

The heat balance method was operated in a steady state mode in all trials. Stem gauges (SGA-10, Dynamax Inc, Houston) described by Ham and Heilman (1990) were used. The sap flow gauges were installed for transpiration measurements when stem thickness exceeded 9 mm, which occurred at early or mid flowering stage. Canola stems are smooth and needed minimum preparation except removing 2-3 bottom leaves and light sanding of the nodes. Plants were prepared 2 days prior to gauge installation. Two days provided sufficient time for wounds to heal properly. Interplant competition increases internode length in canola. Therefore, fewer leaves were removed in the field grown plants compared to pot grown plants. Before installing gauges, a thin layer of electrical insulating compound (G4, Dow Corning Corp., Midland, Michigan) was applied to improve thermal contact and to protect the heater from moisture condensation (Dynamax 1994). White painted foam insulation, foam 'O' rings above and below the gauges and reflective painted PVC weather shields were used to weather proof gauges (Dynamax 1994). In addition, at least three layers of aluminum foil was wrapped around the system to seal it from temperature fluctuations. The entire soil surface in pots in the indoor studies and the base of the plant in the field were also covered with aluminum foil to avoid the influence of external heat from the soil surface on stem temperature. A constant power supply of 4 V was provided to each gauge heater with a 12 V deep cycle Marine battery. The stem thermal conductivity was assumed to be 0.54 W m^{-2} °C^{-1}, as suggested by Sakuratani (1981). Sheath conductance (Ksh) were estimated from low sap flow periods, either from early morning observations (field study) or from detopped plants (growth chamber study) (Dynamax 1994). When convective heat loss was <5% of the total heat supplied, flow rates were set to zero. Gauge signals were scanned every 30 s using a data logger (Model 10X, Campbell Sci., Logan, UT) and mean values were computed for every 30 minutes and stored. However, data was further averaged to determine hourly means.

Experiment 1

A green house experiment was conducted during 1999 to evaluate the accuracy of the sap flow system. About 15 canola plants were grown in 20 cm diameter clay pots filled with top soil Swinton silt loam. A small amount of peat moss was added in the top 1cm soil surface to reduce surface crusting and thereby ensure good plant establishment. Sap flow gauges were installed on 5 plants with stem thickness more than 9.0mm (3 July 1999). Another 3 gauges were installed on plants with less than 9.0mm thick stems. In the evening of 6 July 1999, each pot was watered to field capacity and sealed in a plastic bag to avoid significant transpiration losses. The following day (7 July 1999) sap flow and transpiration (by manually weighing pots on a electronic balance) were measured each hour between 0700 to 1600h. Separate regression for >9.0mm (r^2=0.80) and <9.0mm (r^2=0.48) stem diameters were calculated to determine the accuracy of the sap flow gauges (data not presented). Since the results clearly indicated lower accuracy of sap flow gauges used on stems less than 9.0mm in diameter, data from >9.0mm stems were not included in the study.

Experiment 2

A growth chamber study was conducted in 2000 to determine the effect of temperature on sap flow /transpiration of canola. Crop establishment was similar to experiment 1, except 2 L milk cartons were used in this experiment. The day/night temperature in the growth chamber was maintained at 18/15 °C in a 16/8 h light and dark cycle. When stem thickness reached 9.00mm, sap flow gauges were installed on 8 selected plants and pots were enclosed in a plastic bag to avoid evaporation and moved to temperature controlled growth cabinets. In the growth cabinets, day/night temperatures from 16/15 to 40/15 °C were randomly imposed over the next 8 day period with a 16 h light cycle started at 0500 h and ended at 2100h. To avoid a temperature spike due to sudden shift to day time higher temperatures, increase in temperatures were implemented in three hourly steps between 0500 to 0800 h. All pots were weighed at 0800 and 2100 h. They were watered to 90% of field capacity at

2100 h. Daily transpiration was estimated as the difference between morning and evening weights. Diurnal trends in transpiration were measured during 18/15 °C and 32/15 °C days.

Experiment 3

A field trial was conducted to study the sap flow response to changes in solar radiation. The crop was seeded with an air seeder on 24 April 2000 and at the 4-6 leaf stage the experimental area was manually thinned to 80 pl m^{-2}. The experimental location received 246 mm of rainfall (168 mm is the long term average rainfall) between May to August and 80 kg N, 25 kg P_2O_5 and 22 kg S ha^{-1} fertilizer. When the stem thickness was >9.00mm, 3 plants were selected in different parts of the field for sap flow gauge installation. Sap flow gauges were installed on 25 July 2000 following the procedure described above. The experimental data was collected between 28 July and 2 Aug 2000. Solar radiation (W h^{-1} and W d^{-1}) measured using 1 m long tube solarimeters ("Monteith pattern" tube solarimeter, Delta-T Devices Ltd. Cambridge, UK) for the period was collected from the weather station located about 200 m from the experimental plot. Solar radiation varied significantly during the experimental period. For example, solar radiation on 28 July was 137% higher than that of 2 August. Therefore, heat flux components for those two days were collected for detailed comparisons. Integrated sap flow for the each day between 28 July and 2 Aug was regressed against total solar radiation for the respective day to determine the effect of solar radiation on plant transpiration.

Data Analysis

Data from hourly sap flow observation made on 7 July 1999 in experiment 1 and experiment 2 for days with 18/15 and 32/15 °C temperature regimes were regressed against gravimetrically measured transpiration using JMP statistics software (Sall and Lehman 1996). Similarly, daily sap flow measurements for experiments 1 and 2 were compared with daily transpiration by regression analysis. The slopes of hourly and daily sap flow rates against transpiration were compared with 1. The relationships between sap flow or transpiration with daytime temperature from experiment 2 and the relationship between sap flow and solar radiation from experiment 3 were fitted with second order regression. For all the regression analysis mean observations from 3 to 8 sap flow gauges were used.

RESULTS AND DISCUSSION

Sap Flow and Transpiration

The comparison of hourly sap flow rates with transpiration rates on three different dates are presented in Fig. 1. Hourly sap flow rates during the observation period ranged from 11 to 35 g h^{-1}, which was comparable to that of soybean (*Glycine max* L.) and sunflower (*Helianthus annuus* L.) (Sakuratani 1981), corn (*Zea mays* L.) (Kjelgaard et al. 1997), and potato (*Solanum tuberosum* L.) (Gordon et al. 1997), but was higher compared to prairie grasses (Senock and Ham 1995). Therefore, the sap flow rates during the trial periods were large enough to evaluate sap flow gauges.

A significant relationship between sap flow and transpiration rate (r^2=0.93, n=27) was observed with a RMSE of 2.34 g h^{-1}. The slope was highly significant ($P<0.001$) and did not differ from 1 at $P<0.05$. Similar relationships between short term sap flow rates and transpiration rates have been observed in corn, potato (Kjelgaard et al. 1997) and sunflower (Grime et al. 1995). The variation in flow rates in the present experiment was primarily due to differences in environment. The data from experiment 2 were collected when the day time temperature in the growth cabinet was either 18 °C or 32 °C, while the temperature in the green house varied with solar radiation.

Observation of heat flux components in the green house trial revealed that sap flow closely followed convective heat loss (Qf) (Fig. 2). Under typical daytime evaporative demands, the time constant for the heat balance system is small (< 1 min) (Baker and Van Bavel 1987). Therefore, the sap flow system was effective in tracking transpiration over a short period. The axial heat (Qv) component was the smallest of all the heat flux components and variations in Qv over the period of observation were minimal. Radial heat loss (Qr) was the major component in the beginning of the diurnal cycle and decreased gradually with the increase in the Qf. Prior to 1100 h, Qf was greater than Qr and accounted for more than half of the total heat input (Q). However, as the day progressed, increasing fog reduced Qf slightly and increased Qr slightly to similar values maintained throughout much of the afternoon. The T_{in}-T_{out}, change in sap temperature, for most part of the day was around 1.5 °C. Theoretically, T_{in}-T_{out} increases as sap flow increases, till it reaches the peak (Senock and Ham 1995). Any environmental conditions that reduced sap flow, such as fog restricting radiation, decreased the T_{in}-T_{out}.

Comparison of sap flow and transpiration over short periods in greenhouse and growth chamber conditions indicated that sap flow was over estimating water use (Fig. 1 and 2). Similar observations have been reported by Ham and Heilman (1990), Rose and Rose (1998) and Grime at al. (1995). Among the heat flux components, Qv and Qr are obtained by sensor measurements, while Qf is estimated as residual heat (Baker and Van Bavel 1987). Since, sap flow is directly proportional to Qf, any factor that affects the proper measurement of Qv and Qr will result in inaccurate estimation of Qf. In general, Qv is very small (Fig. 2) and plays a minor role in influencing Qf (Sakuratani 1981; and Ham and Heilman 1990). Qr depends on the thermal conductivity of the gauges and on the radial temperature gradient. Thermal conductivity varies for each gauge and for each installation (Senock and Ham 1995). Therefore, proper estimation of thermal conductivity, which is very difficult under low sap flow conditions or under green house or growth chamber conditions (Senock and Ham 1993), is essential for accurate measurement of sap flow (Rose and Rose 1998). In addition, ignoring the heat storage term (Grime et al. 1995), direct heating of the stem (Senock and Ham 1995), and estimating sap flow temperature from measurement of stem temperature assuming thermal equilibrium (Ham and Heilman 1990) contribute to significant errors in sap flow measurement.

Similar to hourly flow rates, sap flow and transpiration were highly correlated, however, sap flow rate tended to slightly overestimate transpiration when comparing daily flow rates (r^2=0.83 n=66 RMSE=48 g d^{-1}) (Fig. 3). The intercept was not significantly different from zero and slope was not significantly different from 1 at $P<0.05$. Kjelgaard et al. (1997) found gauge performance better when measuring daily flow rates than short period flow rates. Short period flow rates are affected by sensitivity of sap flow gauges to external conditions, warming up of gauges by direct radiation, sap flow temperature variation due to atmospheric conditions, and capacitance of the plant. Therefore, similar accuracies between short period or daily measurements suggests that sap flow gauges can be successfully used in both situations in canola.

The mean error of sap flow system in estimating transpiration over 1 h periods was 11.9% and over a day was 11.1%. The slopes of the regression line were not different from 1, although sap flow tended to overestimate transpiration. The relatively low sap flow rates under greenhouse and growth chambers might have contributed to the error associated with sap flow system (Senock and Ham 1995). These observations were made under different temperatures and varying radiation levels, which in spite of good insulation, have been reported to affect gauge performance (Senock and Ham 1995). However, sap flow rates will be generally higher under field conditions (Zhang and Kirkham 1995) and direct effects of solar radiation and temperature will be less in a canopy than for a individual plant because of continuous shading of gauge setup in the crop canopy. Therefore, we suggest that the sap flow gauge accuracy will improve under field conditions. If future studies also suggest a small overestimation of transpiration by sap flow system, then a correction factor as suggested by Rose and Rose (1998) can be used to reduce gauge error. Sap flow gauges used in this study were sensitive enough to follow short term (1 h) and longer term (daily) water use pattern of canola. Therefore, we suggest that the heat balance technology can be used to measure realtime water use by canola.

Temperature Response

Temperature influences water use directly through its influence on plant metabolic activity and indirectly through increasing the vapour pressure deficit. In the present study, sap flow and transpiration increased in response to increases in day time temperature (Fig. 4). A quadratic function described the relationship between sap flow or transpiration and temperature (r^2= 0.94 to 0.96). In general, there was no significant difference between sap flow and transpiration. Transpiration by canola increased with air temperature up to 36 °C and then declined. Low temperatures reduce transpiration in canola (Ali et al. 1998), however information on the effect of high temperatures is not available. The relationship between gravimetrically measured transpiration and temperature was similar to that between sap flow and temperature. The diurnal trends of sap flow indicate that the daily peak transpiration at 40 °C day time temperature was much lower than at 36 °C day time temperature. Assuming the actual water content of air did not change, the water deficit in the air would increase exponentially with increasing air temperature (Campbell and Norman 1998). Hence, the transpiration increased with increase in temperature. The decrease in transpiration at >36 °C temperature suggests that canola responds to high temperature by closing its stomata (Salisbury and Ross 1992) to reduce water loss. This may be due to the inability of the root system to replenish the higher levels of water lost by the leaf (Salisbury and Ross 1992) or a rise in respiration rate at higher temperature (Whitfield 1992) leading to high levels of internal CO_2 to close stomata.

Response to Solar Radiation

Response of sap flow to solar radiation was evaluated in the field trial in 2000. Solar radiation on a sunny day follows a bell shape curve (Fig. 5). On July 28, the diurnal sap flow pattern was very similar to the diurnal solar radiation pattern, initially increasing rapidly with solar radiation and flattening during middle of the day and later decreasing rapidly as radiation decreased. Similar observations have been reported by Allen and Grime (1995). The solar radiation on 2 August was very low due to cloud cover and was near zero between 1400 and 1500 h due to thunder shower (Fig. 6). However, the clouds cleared later in the day.

Sap flow trends on that day also followed solar radiation trends closely, however, the relationship was not as strong as on the previous sunny day. Sap flow gauges are less sensitive at lower sap flow rates due to longer time constants, which was also observed in other studies (Gordon et al. 1997). The daily solar radiation during the experimental period, which ranged from 3250 to 7790 W m^{-2} d^{-1} was regressed against the integrated sap flow during the day (Fig. 7). The relationship was significant (r^2=0.97) with RMSE of 14.8 g d^{-1}. This indicates sap flow in canola is highly dependent on solar radiation.

Components of heat balance on a sunny day and on a cloudy day are presented separately to show the comparative importance of each heat flux component under different radiation environments (Fig. 5 and 6). On a sunny day of 28 July the heat flux components followed theoretical trends. At the beginning of the day, Qr was the largest component (up to 0.92 of Q) of the heat balance which decreased gradually with increasing Qf in response to increasing sap flow. Peak Qf (0.59 of Q) was reached at 1340 h and, for most of the midday, Qf was accounting for more than 50% of Q. Although, a similar fraction of Qf have often been observed at moderate flow rates, at higher flow rates (above 50 g h^{-1}) higher fraction of Qf (about 0.90 of Q) have been reported (Senock and Ham 1993). In contrast, on a cloudy day Qf accounted for around 10% of Q for most of the day and reached a maximum of 26% of Q at 1700h. Therefore, Qr accounted for most of the Q during a day with low sap flow. The accuracy of estimating transpiration reduces with any small error associated with estimating Qr (Senock and Ham 1993; Gordon et al. 1997). Overall, the quick response of sap flow gauges to the radiation environment suggests that sap flow gauges using heat balance concept can be successfully used under field conditions to estimate transpiration rates.

SUMMARY

A commercially available heat balance sap flow system was evaluated for measuring transpiration of canola. Both short term (hourly) and long term (daily) observations of sap flow correlated well with transpiration measured gravimetrically. Although, the sap flow gauges were overestimating transpiration by an average of 11%, better accuracy is presumed for measurement in a crop canopy under field conditions. Water use of canola in response to temperature followed a quadratic relationship, increasing with increasing temperature until a threshold temperature (36 °C) was reached and decreased thereafter. The reduction in water use at high temperature was attributed to stomatal closure. The sap flow gauges showed the response of transpiration to radiation input. The relationship between solar radiation and sap flow was significant (r^2=0.97). Thus, the sap flow system showed promise for estimating transpiration in canola. The sap flow gauges using heat balance method can be used for many agronomic and physiologic studies of canola.

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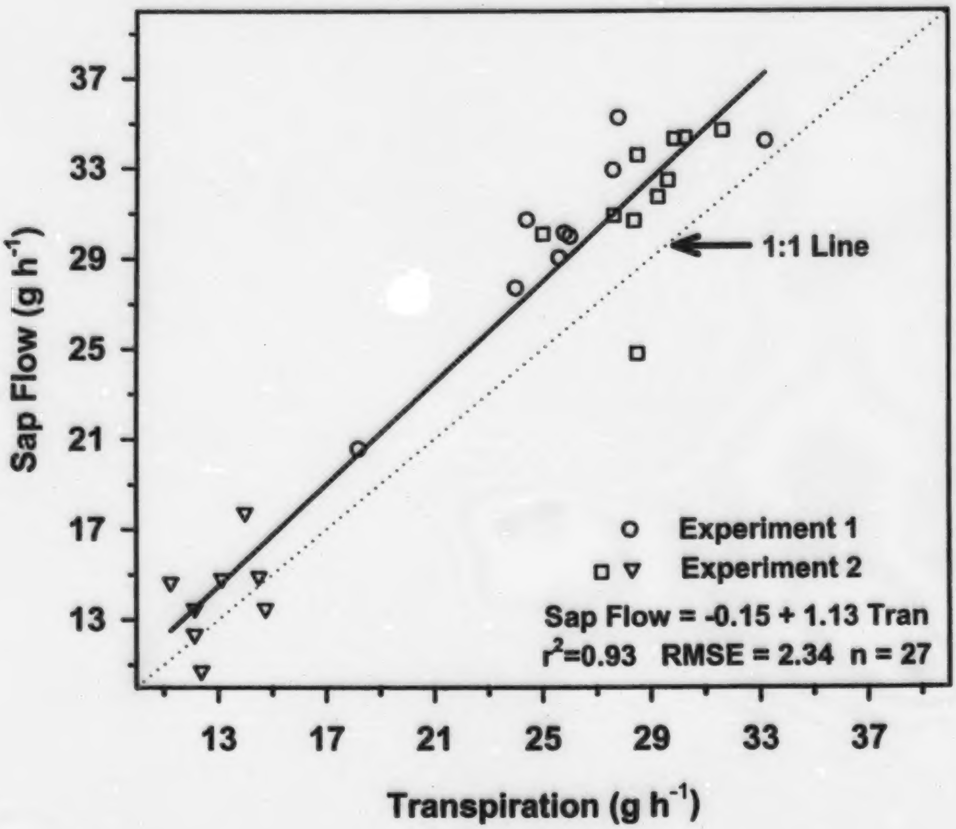

Fig. 1. Comparison of the hourly transpiration rate (g h^{-1}) measured by the gravimetric method with the sap flow rate (g h^{-1}) measured by the heat balance method in canola for one day in 1999 during green house study (Experiment 1) and on two days in 2000 during the growth chamber study (Experiment 2), respectively.

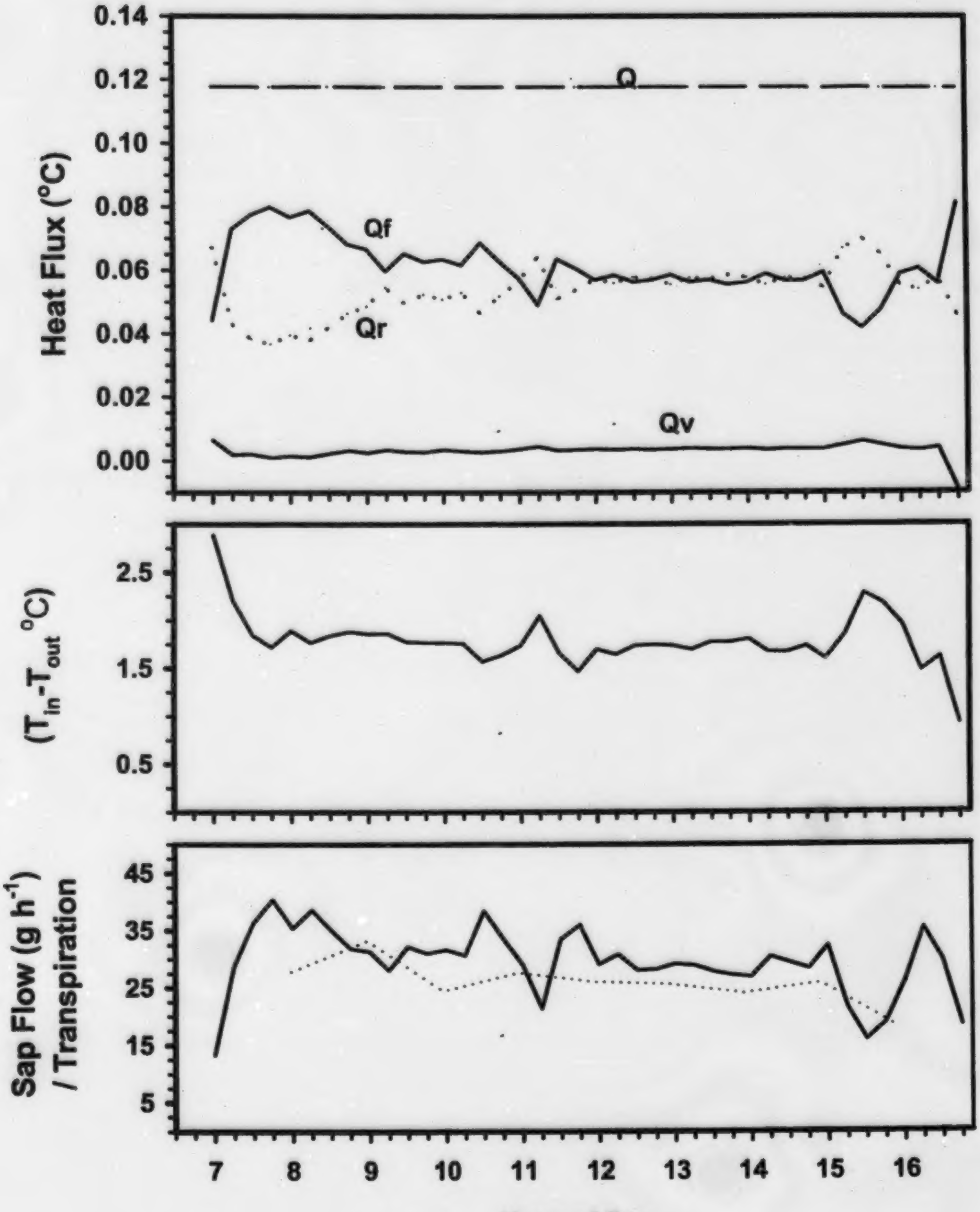

Fig. 2. Sap flow gauge heat balance components measured in the greenhouse on July 8, 1999. (a) The heat balance parameters include heat input (Q), radial heat loss (Qr), axial heat loss (Qv) and convective heat loss due to sap flow (Qf). (b) Difference in incoming and outgoing sap temperature. (c) Sap flow measured by the heat balance method (solid line) and transpiration (dotted line) measured by the gravimetric method during the observation period.

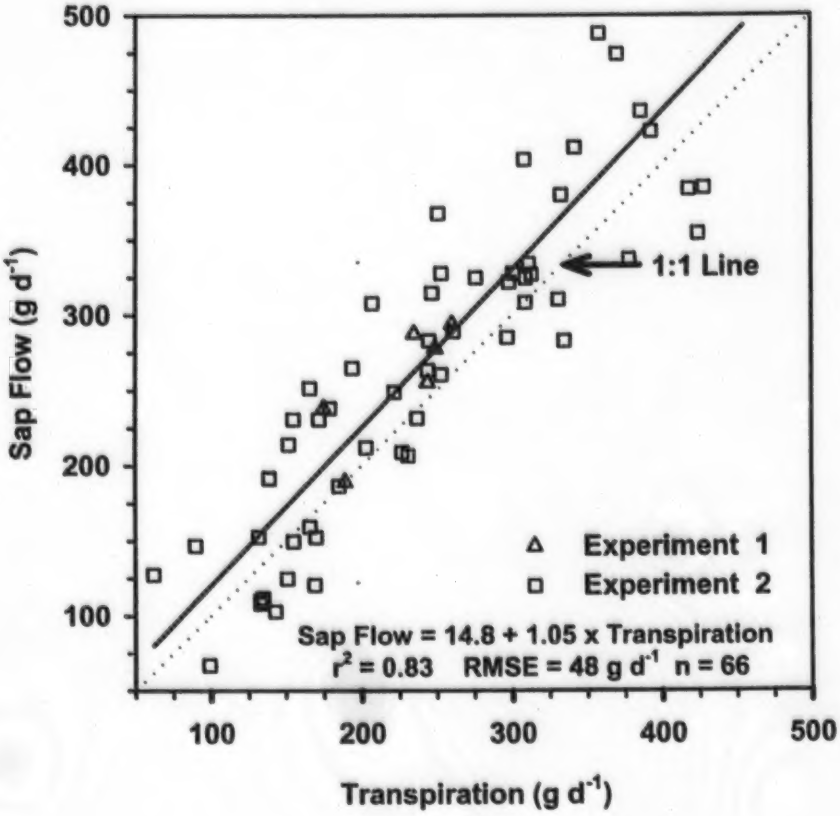

Fig. 3. Comparison of the daily transpiration rate (g d^{-1}) measured by the gravimetric method with the sap flow rate (g d^{-1}) measured by the heat balance method for canola during the green house study in 1999 (Experiment 1) and during the growth chamber study in 2000 (Experiment 2).

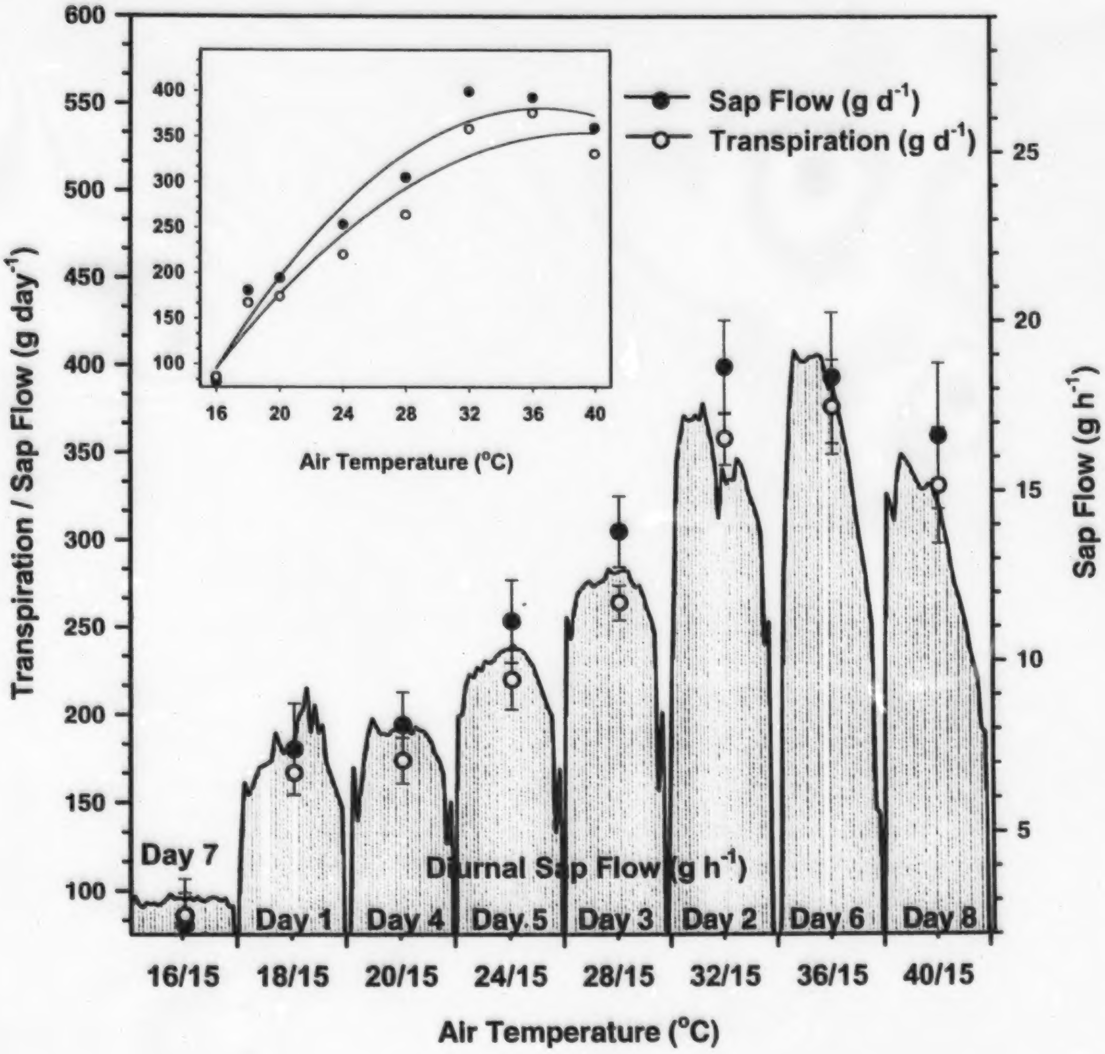

Fig. 4. Response of daily transpiration (open circle) (g d^{-1}) and daily sap flow (Solid circle) (g d^{-1}) rates between 0800 and 2100 h to variations in day time temperature. Vertical bars are S Em±. Relationships for sap flow and transpiration with day time temperature (inset graph) were $Y = -520.4 + 49.2 X - 0.67 X^2$ ($r^2 = 0.96$) and $Y = -381.1 + 37.4 X - 0.47 X^2$ ($r^2 = 0.94$), respectively. Also shown in the diurnal response of sap flow to the variation in in day/night temperature regimes. The day/night temperature regimes as indicated by day numbers were randomly applied.

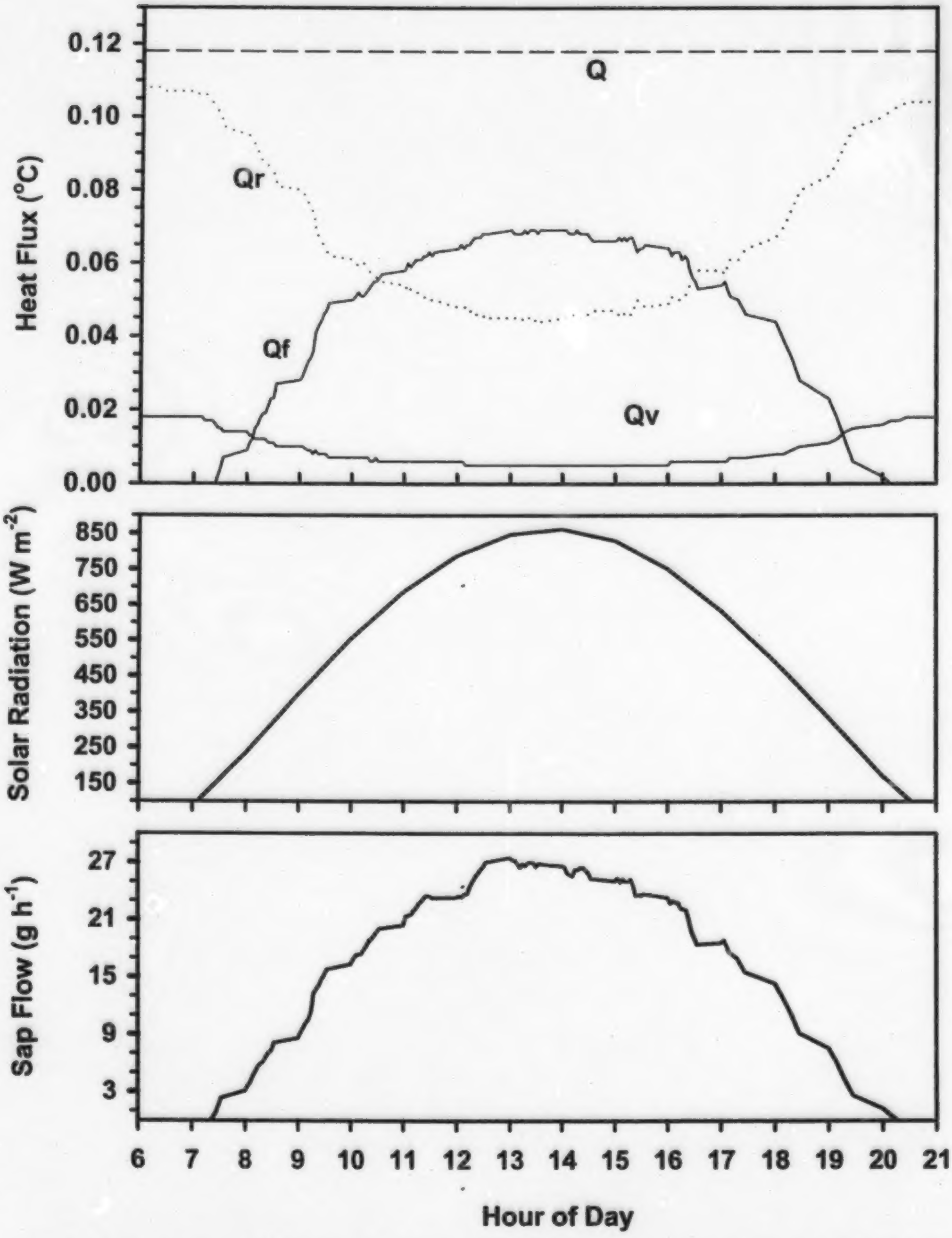

Fig. 5. Sap flow gauge heat balance components measured in the field during the active transpiration period on the sunny day of July 28, 2000. (a) The heat balance parameters include heat input (Q), radial heat loss (Qr), axial heat loss (Qv) and convective heat loss due to sap flow (Qf), (b) Solar radiation (W m^{-2}), and (c) Sap flow (g h^{-1}).

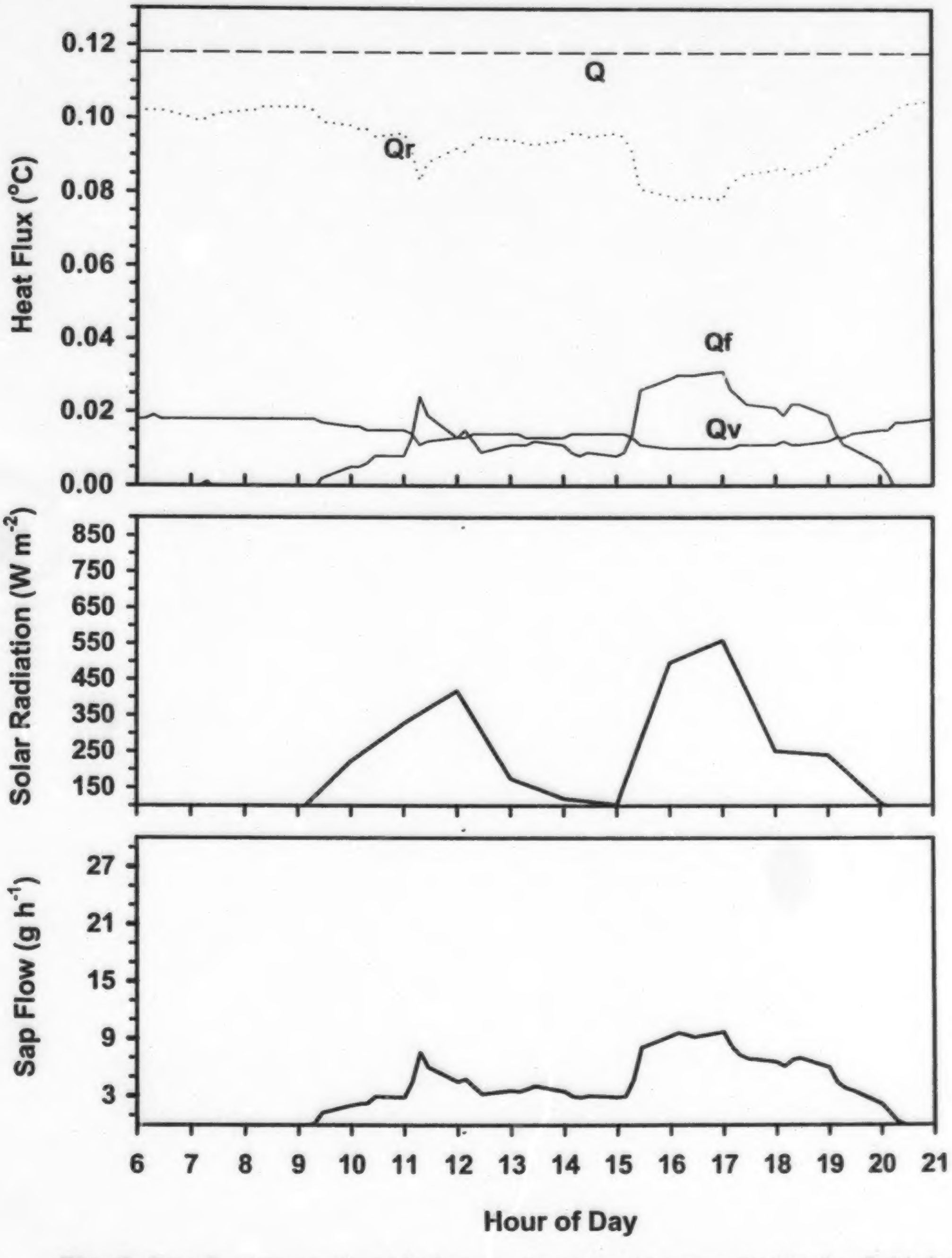

Fig. 6. Sap flow gauge heat balance components measured in the field during the active transpiration period on the cloudy day of August 2, 2000. (a) The heat balance parameters include heat input (Q), radial heat loss (Qr), axial heat loss (Qv) and convective heat loss due to sap flow (Qf), (b) Solar radiation (W m^{-2}), and (c) Sap flow (g h^{-1}).

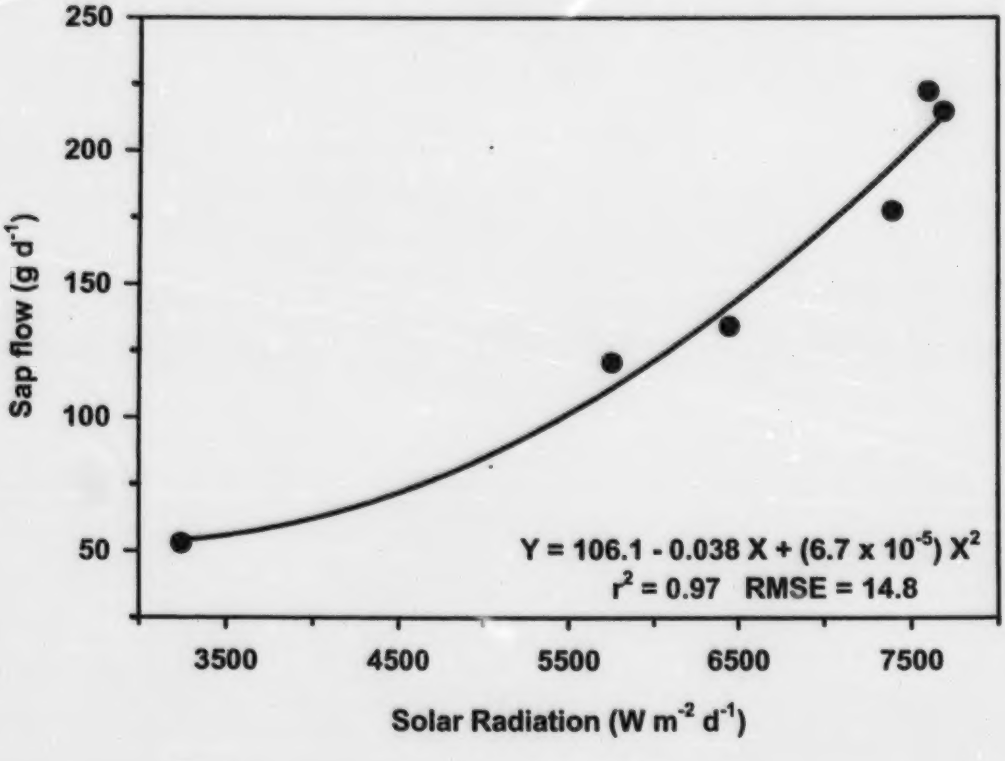

Fig. 7. Relationship between solar radiation (W m^{-2} d^{-1}) and daily sap flow (g d^{-1}) for field grown canola from July 28, 2000 to August 2, 2000.

D. PERSONNEL

Name	Salary/month
Sangu Angadi	
Jason Newton, Cory Wooff, Joseph O'Denelli	

E. EQUIPMENT

N/A

F. PROJECT DEVELOPED MATERIAL

- **Angadi S.V.,** Cutforth H.W. and McConkey B.G. 2002. Determination of the Water Use and Water Use Response of Canola to Solar Radiation and Temperature by Using Heat Balance Stem Flow Gauges. (Submitted to *Can. J. Plant Sci.*)
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- **Angadi S.V.,** Cutforth H.W., and McConkey B. 2000. Seeding management to reduce temperature stress in Brassica species. p. 435-439. *In* Proc. the Soils and Crops Workshop. Univ. of Saskatchewan. 24-25 February, 2000. Univ. Ext. Press, Saskatoon, SK, Canada. (Poster Presentation).

G. PROJECT PHOTO

See Chapter 3 of Technical Report.

H. ACKNOWLEDGMENT

Preliminary results from the experiments of this project were presented in Canadian Society of Agronomy, American Society of Agronomy, and Saskatchewan Soils and Crops Workshops. These trials were discussed at field days organized for farmers, agronomists and policy makers from both Canada and USA. An interview on the possibility of seeding canola and mustard in the fall was broadcasted on CJFB television. The funding sources for this study were acknowledged at all the meetings, workshops and conferences where this data was presented.

I. EXPENSE STATEMENT

See attachment.